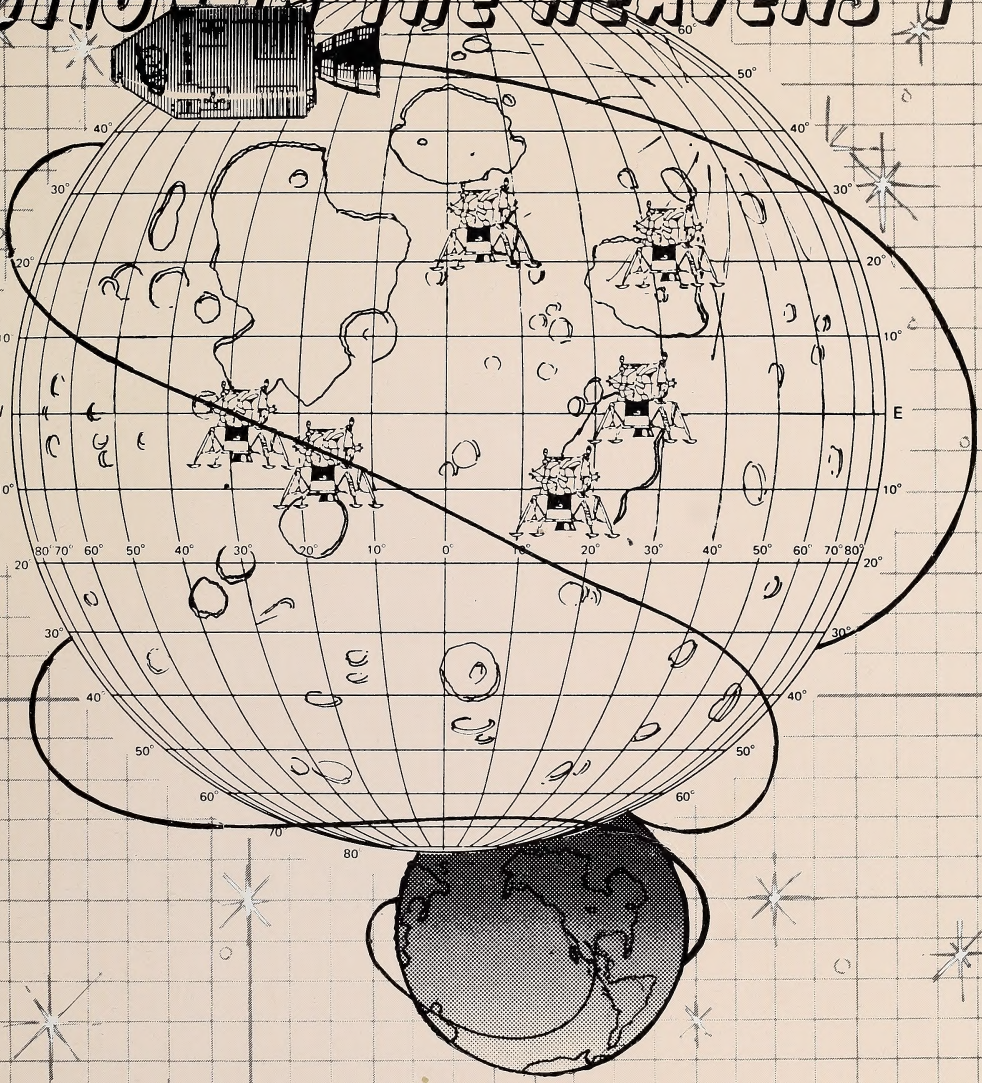
MOTION IN THE HEAVENS 1



PHYSICS 10

«Elective A»

Alberta Correspondence School,
Alberta Education,
Barrhead Alberta.

Physics 10

Elective A

MOTION IN THE HEAVENS 1

Distance Learning

Alberta EDUCATION

ISBN No. 0-7741-0032-X

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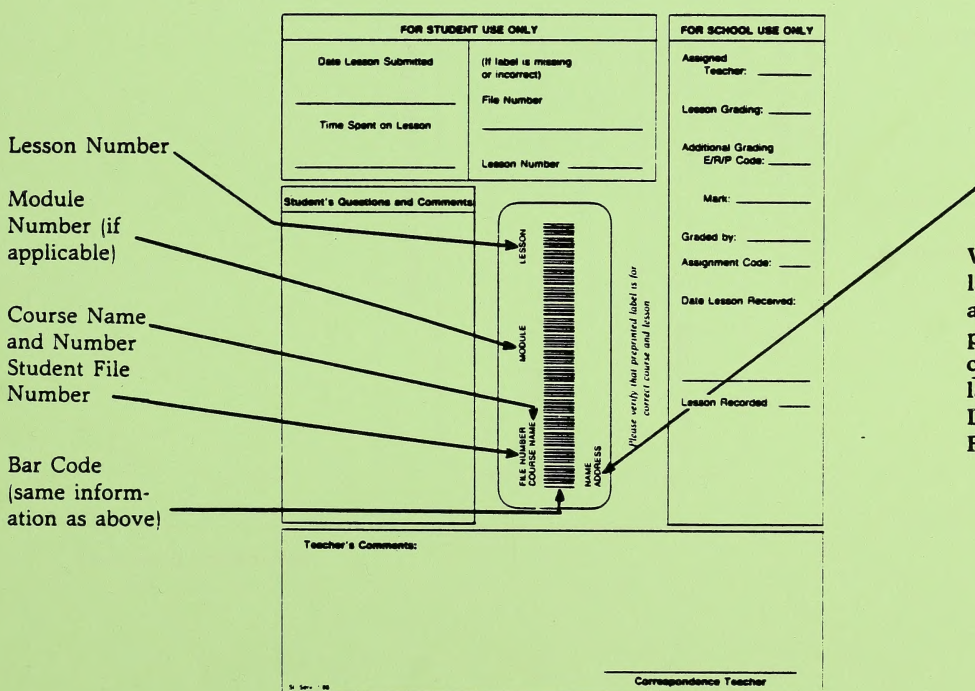

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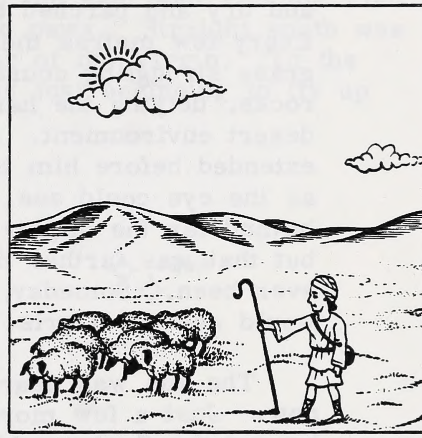
OBSERVING THE HEAVENS

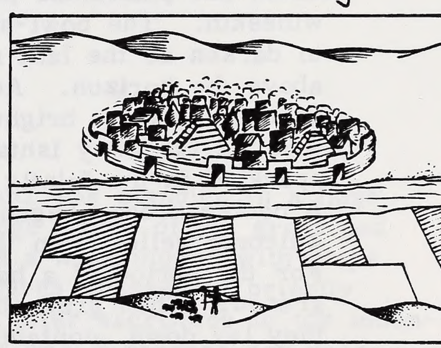
An Ancient Astronomer



The hot sun beat down on Kahlil the shepherd as he led his flock along the edge of the greenland. It was late in the afternoon now but the hot puffs of breeze continued to rustle through the green blades of barley to his left. He would need to press his flock hard, for the pasture was becoming scarcer. The last rain had fallen over two weeks ago and the land away from the river was already becoming harshly dry. Kahlil gazed with a twinge of longing toward the cool dark Euphrates flowing slowly and calmly southward. Between his flock and the river, rich red-brown freshly ploughed earth alternated with green waving blades of barley and wheat. The power of Enki lay within those depths of cool fertility. Would Enki's power devastate the rich green valley again this year? Would his rushing waters cover the land?

Just last evening as the land darkened following sunset, he had seen Aldebaran, the red eye of the bull, twinkling low in the western sky. The time for the river's fullness was near. But now his thoughts and his feet had to turn away from the river. He and his flock began the gentle climb from the greenland to the pastures above the shallow river valley. When they reached the top Kahlil looked back for a moment over the lush valley. The city of Babylon lay basking in the distant haze. The great holy hill of the moon-god Sin rose as a huge mound through the haze. Life was now improving thought Kahlil, since King Hammurabi was assigned by the great and wonderful Marduk to rule the city. The king was just and humble and a great man.

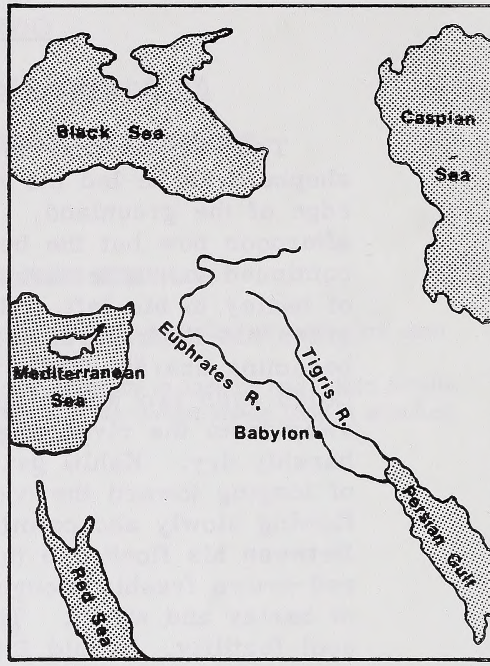
Aldebaran – the 14th brightest star in the sky. It appears low in the west after sunset late in May



Hammurabi was king of the first Babylonian Empire about 1800 B.C. He formulated a famous ancient code of laws.

Marduk was chief god of the Babylonian pantheon (council of gods). Originally he was a successful warrior god. It was thought that the king was Marduk's agent on earth.

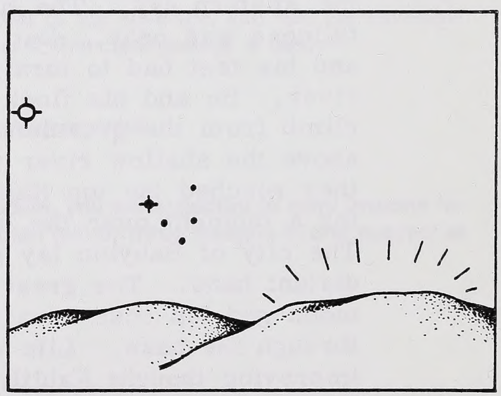
The bleating of the lambs brought his wandering thoughts back to the job which lay before him. The upland stretched before him, strewn with roeks, and dry and parched by the hot sun. Every few metres there were tufts of grass struggling courageously among the rocks, defying the harshness of the desert environment. The dry land extended before him to the east as far as the eye could see. Somewhere beyond lay the mighty Tigris River, but that was farther than Kahlil had ever been. Someday, he thought, he would see the Tigris.



Tigris and Euphrates Rivers

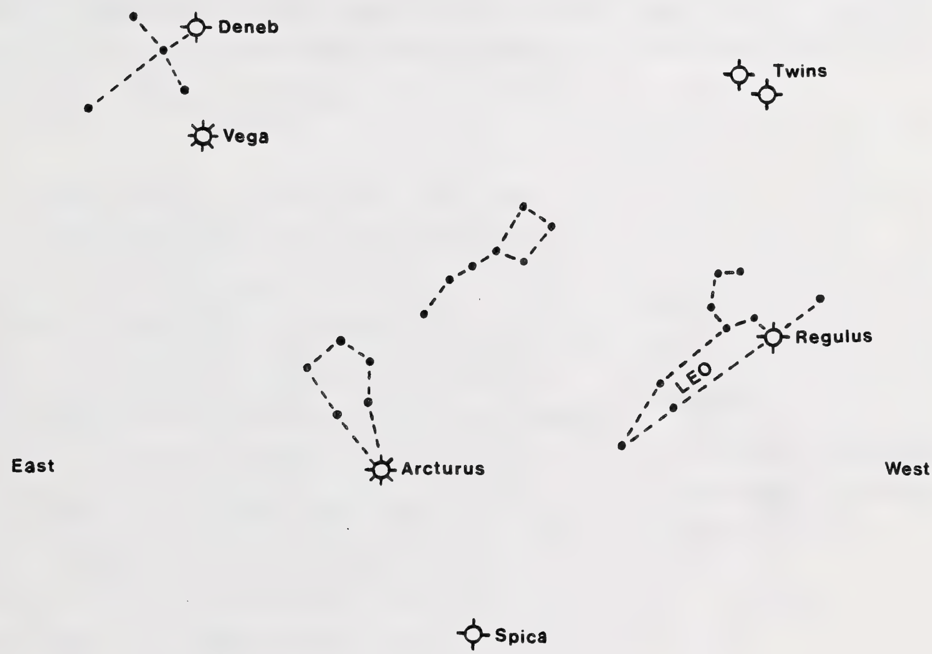
The sun was nearing the horizon now. Just a few more kilometres and he and the flock would stop for the night. Kahlil grasped his staff and pressed on. The shadows were lengthening.

Just as the sun was setting, Kahlil stopped his flock. They were happy to begin grazing on the tufted grass. Kahlil was hungry. With some enthusiasm he untied the cloth which held his lunch and pulled the plug from the wineskin. The bowl-shaped sky began to darken as the last rays spread out above the horizon. And there, surely enough, was the bright red Aldebaran. And not far away Ishtar glowed and sparkled in the faintly lit western sky. A cooler breeze began to blow now – a welcome relief from the heat of the day. For the period of a half hour his flock grazed. Then gradually, one by one, they lay down, content but tired from the long, hot day.



Ishtar and Aldebaran

Kahlil was tired also and using his knapsack as a pillow he lay down. By now the sky was growing darker and the brighter stars began to appear in the bowl of the heavens. In the west were the bright twin stars. Following close behind in the east was Leo the Lion with his huge head and body and his extended paws. Straight south was Arcturus in the Herdsman and the bright star of the Virgin. To the east the Lyre had appeared and the Swan was just beginning to fly up from the horizon.



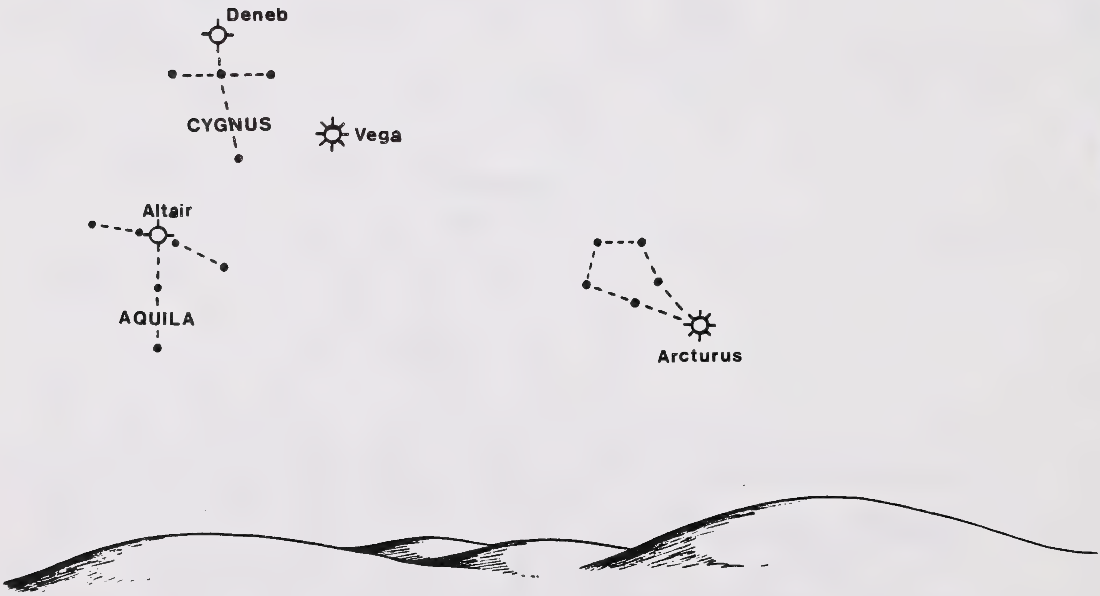
Gradually the sky began to fade and Kahlil was standing in a huge dome-shaped temple. At one end stood a huge figure of the great god Marduk. On the other side of the dome was a huge mound with steps leading to the top. A long succession of figures dressed in priestly robes were slowly ascending the stairway to offer sacrifices to the moon-god Sin. Suddenly standing there beside him was Ninhursa, her robe flowing downward and trailing behind her and her hair fragrant with spring flowers. Kahlil's heart leaped for joy.

"Ninhursa, why are you here?"

"I dreamed of you last night Kahlil and I wanted to see you again."

Kahlil took her hand and slowly they walked toward the great image of Marduk. Suddenly Kahlil heard a rustle and the bleating of sheep. He sat up with a start rubbing his eyes. A wolf was standing over a lamb. Quickly Kahlil grasped his staff and rushed toward the animal, driving it away. I must get a dog, he thought, to warn of the approach of these ravenous beasts.

He looked at the stars again. By now Aquila the Eagle had risen above the horizon. He must have been sleeping for several hours. He would need to check over his flock to see that no more had been harmed. Only then could he again relax, enjoy the starry scene spread before him and turn his thoughts to his beloved.



You have just been observing an early and very amateur star gazer. Kahlil's experience, however, illustrates how ancient man viewed the sky — with a mixture of observational accuracy and mythological reverence. The sky was both a timepiece and a temple. It appeared to have a certain shape and its objects were filled with personality as they moved about from day to day and season to season. Part of our task in this lesson will be to learn a bit about the shapes in the sky and even something about the personalities that the ancients put there.

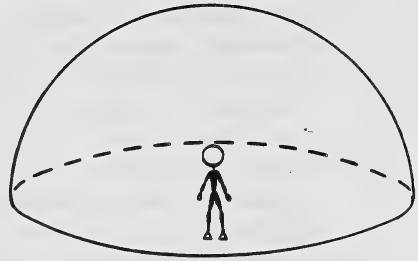
The sky— a timepiece and a temple

Thus much of this lesson will deal with knowledge that has been around for thousands of years. In fact the ancient peoples of Mesopotamia and Egypt were probably much more familiar with the sky than we in the 20th century are, simply because they were exposed to it more. Electricity and atmospheric pollution have helped to obscure much of the sky to modern urban dwellers. The invention of clocks and watches has made it unnecessary for the common man to tell time by the stars or the sun. Thus though we may know more about the mechanics of the universe and how it operates, the ancients were probably much better acquainted with the night sky itself. This lesson, we hope, will help to increase our knowledge and recall some of the things that man has known about the sky for a long time.

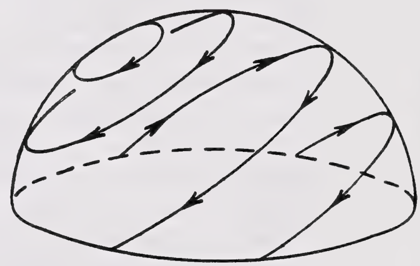
Ancient peoples more familiar with the sky than we are?

The Appearance of the Sky

Suppose that you had never seen the sky before, that you had grown up underground. What would you see the first time that you were brought above ground and exposed to the night sky? No doubt you would see what the ancient peoples saw. If you stood on a level plain the earth would appear to stretch before you as a level surface, appearing to form a circle where the horizon meets the sky in the distance. If the atmosphere is clear the sky would look something like the inside of a huge inverted bowl, pale blue with occasional clouds during the day except near the brilliant disc of the sun, and very dark, almost black, at night with thousands of lights dotting its surface. If it were daylight you would notice if you observed several hours that the sun had moved and gradually was approaching the horizon. Eventually it would slip below the horizon and after about half an hour tiny pinpoints of light would appear. These points, too, would move gradually across the sky, each appearing to describe a circle as time passes. Some of the points of light would describe small circles. Others would seem to come up from one horizon, describe a semi-circle across the bowl and disappear behind the other horizon.

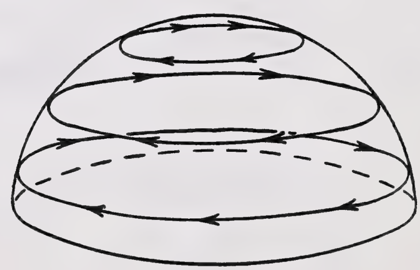


The Sky as a Dome

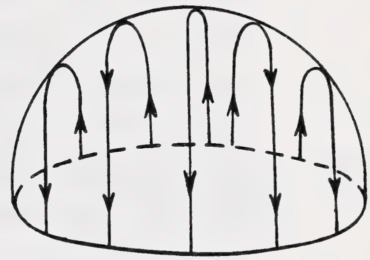


If you were willing to travel and you moved for a long period of time toward the stars which move in complete small circles you would come to a land of perpetual ice and snow. The stars would all appear to describe complete circles.

Where would you be? ____________________.



If now you travelled in the opposite direction until you came to a land of warm, humid temperatures with dense growth of all kinds of trees and plants you would find that <u>all</u> of the stars describe semi-circles and all of the stars rise and set. Where would you be?



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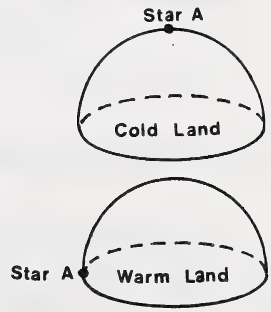
As you continued to observe the sky you would find that one of the stars seems to move hardly at all from hour to hour. Yet as you go from the middle of the cold land to the middle of the warm land you find that this star moves from straight above you right down to the horizon. This star is most often identified as the north star or Polaris.



<u>To think about</u>: How can you explain the change in position of the north star as you go from the cold land to the warm land?

How can we explain the movements in the heavens?

In this and the next lesson we want to think about ways to explain the motions of the stars and sun. This was one of the most vexing problems for ancient philosophers.

<u>Continued Observation of the Sky</u>

If you continued to observe the sky it would not be long until you discovered that there were four kinds of objects there. The brightest and most important, of course, is the sun. The next brightest, the moon, appears to be about the same size as the sun and much less bright but brighter than the stars.

Sun
Moon
Stars
Wanderers

It would take a little longer to discover that there are different kinds of stars. Most of them remain in fixed positions in relation to each other. But there are a few, usually much brighter than the others, which appear to move among the rest of the stars over a period of days and months. The Greeks called them planets (from planetein "to wander"). The star Ishtar which Kahlil saw in the story was the wanderer Venus.

1. Fixed Stars

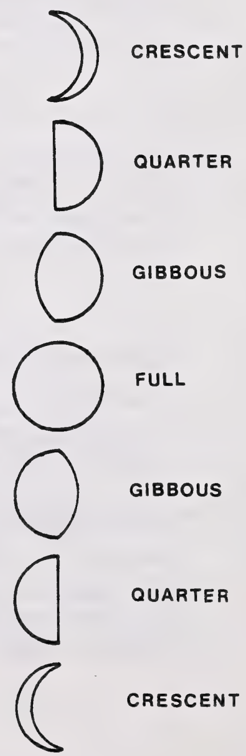
2. Wanderers → Planets

The Motions of the Moon and Sun

The most obvious motion is that of the sun during the day as it moves from rising in the east across the sky to setting in the west. Some of the stars follow the same pattern as we have seen earlier, while others appear to move in circles without rising or setting. The whole heavenly sphere appears to make one turn daily.

The sun, moon and some stars rise and set daily

There is something unusual about the moon, however. The moon often appears in the sky after the sun has set. Each night it moves farther and farther to the east. Sometimes it occults (hides) a star. It rises later and later each night until it rises just before the sun. Then it disappears for a while but soon reappears in the western sky just after sunset. Not only does it move about in this interesting way, it also changes shape from a thin crescent to a full circle back to a crescent again. It takes the moon $29\frac{1}{2}$ days to go through this complete cycle, a period which we call a month (moonth).



Phases of the Moon

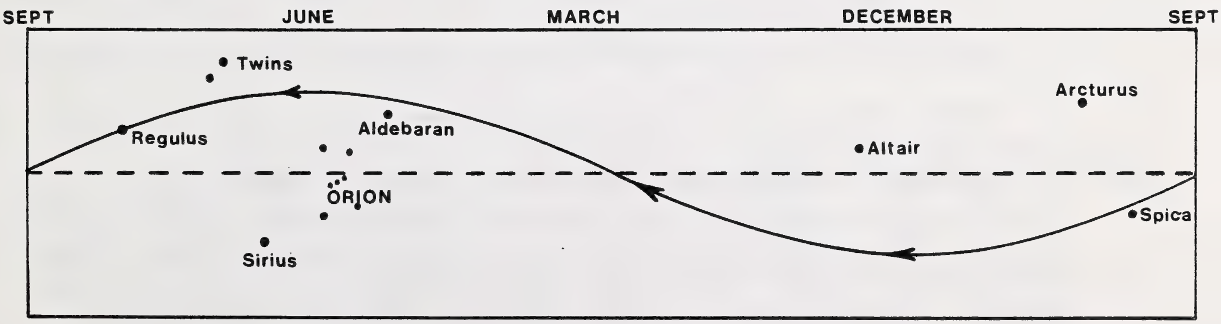
The sun also has some strange movements. It rises and sets every day, but it also moves through the heavens against the background of the stars. This is most easily observed before sunrise. Different stars rise before the sun as the days pass. For example, the bright star, Sirius, rises just before the sun in July. It continues to rise earlier and earlier (or looking at it another way, the sun rises later and later). Thus the sun appears to move always eastward among the stars until it comes back to its starting point to repeat the same cycle. This cycle we call the year.

Sirius - the brightest star in the sky.

The year

As the sun moves eastward among the stars it also appears to move up and down (or north and south). In June it is high in the sky at noon and in December it is very low. If we trace the sun's path on a flat star map it would look like this:

The sun's altitude changes as the year advances.



Yearly Motion of the Sun Among the Stars

This movement up and down throughout the year is responsible for the seasons.

The two periods of time produced by the movements of the moon and the sun (the month and the year) presented a severe problem to ancient civilizations. Their only method for telling time was the motion of heavenly bodies. The problem was the relationship between the month and the year.

Problems

1. It takes the moon $29\frac{1}{2}$ days to make a complete trip through the stars. This is one month. In one year the ancient people noticed that the moon made 12 such trips. How many days are there in 12 months of $29\frac{1}{2}$ days?

2. How many days are there actually in a year?

____

3. What problem does this create? (Hint: Think about the seasons. What happens to the calendar?)

____

____

____

This was a difficult problem for the ancients. The changes in the moon's motion were much more obvious than the changes in the sun's motion. The moon was therefore used to keep account of time. The month began with the first appearance of the moon's thin crescent after sunset. The astronomers of Mesopotamia, using the month as the standard time period, tried several solutions to the problem.

4. Solution 1

   (a) How many days are in a 12 "moonth" year (#1 from the above problems)?

   ____

(b) How many days is this short of an actual year?

(c) How many years would this take to add up to <u>about</u> one month?

(d) Thus every ______ years the astronomers could add one extra month to the calendar.

(e) There is still an inaccuracy, however. How many months would there be in this three year period?

______ months + ______ months + ______ months = ______ months

If each month has $29\frac{1}{2}$ days how many days are there in this period?

______ months × ______ $\frac{\text{day}}{\text{month}}$ = ______ days

How many days are there actually in a three year period of $365\frac{1}{4}$ days per year?

How many days of difference are there between this three year calendar and an actual three year period of $365\frac{1}{4}$ days per year?

5. Solution 2

This solution uses an eight year period with 3 years of 13 months.

Year 1	12 months
Year 2	13 months
Year 3	12 months
Year 4	12 months
Year 5	13 months
Year 6	12 months
Year 7	13 months
Year 8	12 months

(a) How many days are there in this period? (Note – we know now that over a long period of time the "moonth" averages out to 29.53 days).

(b) How many days are there actually in an eight year period?

(c) How many days error is this?

6. Solution 3

A more accurate solution is to use a 19 year period with seven years having 13 months and 12 years having 12 months.

(a) How many months are in this period?

(b) How many days is this period? (Use 1 month = 29.5306 days.)

(c) How many days are there actually in a 19 year period? (Use 1 year = 365.2422 days.)

(d) What is the error in days for this calendar?

(e) How many days does this amount to in 100 years?

In 1000 years?

You can see that if you stick with it long enough you can find a reasonably accurate solution to a difficult problem. Solution 3 above became the basis of the Jewish calendar.

More Solutions to the Problem of the Time Periods of the Sun and Moon

The Egyptians solved the problem a bit more simply by having 12 months of 30 days each with 5 days bonus at the end of the year. This calendar was actually based on the sun's yearly movement rather than on the month. The extra one quarter day in a year, however, adds up to one month in 120 years.

Egyptian solution based on the sun's apparent motion

Our present calendar began with Julius Caesar in 46 B.C. In his day the calendar had become so bad that the first day of spring was in June instead of March. Caesar added eleven days and changed the seventh month to July (named after guess who?) and August became the eighth month. Two days were taken from February and added to July and August. Up to that point March had been considered the first month of the year, <u>Sept</u>ember was the seventh, <u>Oct</u>ober the eighth, etc. Caesar also added one day every four years to February.

The Julian calendar

Even this calendar, however, had sizable errors. In 1582 the first day of spring was March 11. Pope Gregory XIII authorized the omission of 10 days from the calendar in October of 1582. In addition only the century years that were divisible by 400 were to be leap years. Ordinarily all century years would be leap years because they are divisible by four.

The Gregorian calendar

Thus 1900 was not a leap year but 2000 will be a leap year. This is necessary because the year is 365.2422 days, not 365.25 days. This difference seems small but it added up to 12 days between Julius Caesar (46 B.C.) and Pope Gregory (1585 A.D.). This is the calendar that most of the Western World uses and it is called the Gregorian calendar. Its error is one day in about 3000 years.

Accuracy of the Gregorian calendar

Thus it took about [1585 A.D. - (-3000 A.D.)] 4500 years to develop a calendar that would be reasonably accurate. Even then it is a solar calendar, that is, its months do not correspond precisely with the moon's motion.

3000 B.C. = -3000 A.D.

The Motions of the Wanderers

We have noted before that there are several of the brighter "stars" that appear to move against the background of the "fixed" stars. The people of the ancient world were acquainted with five of these. They were called Mercury, Venus, Mars, Jupiter and Saturn after Roman gods. These wanderers moved through the sky at varying speeds, Mercury taking six years to return to a given position amongst the stars and Jupiter 83 years.

The five planets known in the ancient world:

Mercury
Venus
Mars
Jupiter
Saturn

It was early in the history of civilization that another curious fact was observed. It was the fact that the sun, the moon and the wanderers appear to move around in the sky in roughly the same path, no matter how fast or slow the motion occurred.

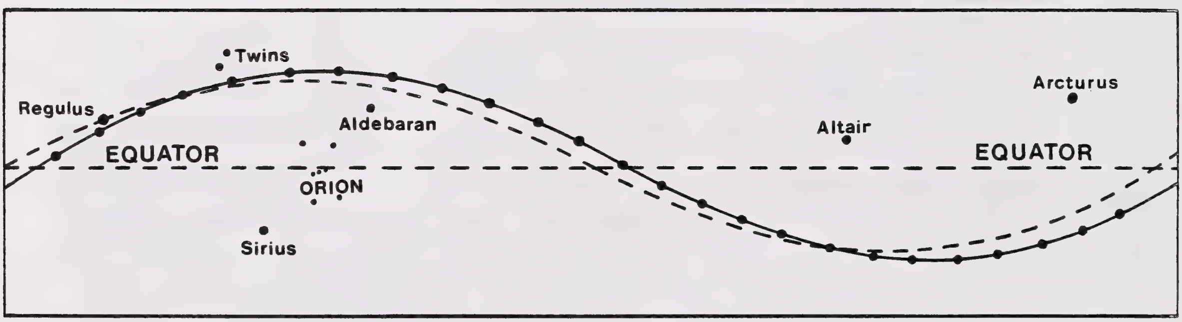
The sun, moon and planets all move within a narrow band in the sky

It was not long until this path was given special recognition since what happened in the skies was thought to have a profound influence on events on earth. This path or zone became known as the zodiac. In astronomical terms the center of this zone is the ecliptic — the path that the sun appears to follow amongst the stars. The moon deviates as much as five degrees from this path while Mercury deviates as much as seven degrees. The paths of all the other planets deviate to some greater or lesser degree from this path.

The zodiac

The ecliptic

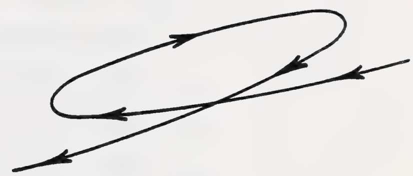
The planets' motions deviate slightly from the ecliptic.



Path of the Moon for October 1972 (distance between dots represents one day)

The curved broken line represents the ecliptic.

The ancients also observed that each of the wanderers did not move with constant speed through the zodiac. Sometimes the movement was quite rapid for a given planet. Other times it was slower. Also it was noticed that at certain times the planet seemed to stop, move backward, stop and then move forward again describing a loop in the sky. This was true for each of the wanderers though the loops varied considerably in size. How does one account for these strange, uneven motions? We will come back to this question in the next lesson.



A Typical Orbital Loop for Mars

Such a loop may take 4 to 5 months to complete

It was also observed that two of the planets Mercury and Venus never went very far away from the sun in the sky. Mercury went a maximum of 28° from the sun and was either an evening star or a morning star, setting after the sun or rising just before it. Venus never went farther than 48° from the sun. All the other planets could have any angle with the sun.

Retrograde Path of Mercury

Questions and Problems

1. The ordinary laborer or herdsman in the ancient world was probably more familiar with the sky than the ordinary person today. Why?

   (a) The ancients had knowledge available to them which has since been lost.
   (b) We live mostly in cities and towns and have clocks.
   (c) The sky was clear for more hours of the year in ancient times than it is now.
   (d) The latitudes of ancient civilizations were more suitable for observation than our latitudes. ________

2. Suppose that you went outdoors in the flat, open land of southern Saskatchewan or Manitoba. You can see to the horizon equally in all directions. What percentage of your total view up, down, east, west, north and south does the sky occupy?

   (a) half
   (b) two-thirds
   (c) one-quarter
   (d) about three-eighths ________

3. At latitudes that are similar to Alberta's which of the following statements is true about the stars?

   (a) All stars describe complete circles in the sky as the hours pass by.
   (b) Some stars rise and set and other stars describe circles in the sky daily.
   (c) All stars rise and set daily.
   (d) Only the stars very near the sun's path in the sky rise and set. ________

4. Which of the following shows the most rapid motion in the sky against the background of the stars?

   (a) moon
   (b) Mars
   (c) sun
   (d) Jupiter ________

5. How could you tell the difference between a planet and a star?

   (a) A planet is always brighter than a star.
   (b) A planet appears closer than a star.
   (c) A planet appears larger than a star.
   (d) A planet appears to move through the stars over a period of time. ________

6. How many days does it take the moon to go from one full moon to the next?

   (a) 29 1/2 days
   (b) 31 days
   (c) 365 1/4 days
   (d) 30 days ______

7. Which of the following calendars do we use?

   (a) Gregorian
   (b) Julian
   (c) Egyptian
   (d) Babylonian ______

8. What is the ecliptic?

   (a) The path the planets appear to follow among the stars.
   (b) The path the moon appears to follow among the stars.
   (c) The path that the sun appears to follow among the stars.
   (d) The point at which the sun is at the beginning of spring. ______

9. Which of the following best describes the motions of the planets among the stars?

   (a) The planets move with some variations in speed, sometimes even appearing to reverse their motion.
   (b) The planets move uniformly with only very slight variations in speed.
   (c) The planets move with large variations in the speed of motion but direction of motion remains the same.
   (d) The planets appear to move west to east about half the year and east to west the other half. ______

10. The brightest star in the sky is

    (a) Polaris.
    (b) Vega.
    (c) Venus.
    (d) Sirius. ______

11. Why is the moon's motion no longer used as the basis for our calendar?

____

____

The Fixed Stars

The fixed stars, as well as the sun, moon, and planets also received their share of attention by ancient sky observers. They served first of all as a background or screen against which the motions of the other bodies were observed. The stars could also be used to tell time. A star day would be the time between successive risings or settings of a given star. Star days are slightly shorter than sun days because the sun appears to move about 1° per day among the stars.

Uses of fixed stars:

- grid for observing motion
- timepiece - rising and setting of stars

Star days and sun days

The brighter stars were honored with names. Many of the stars seemed to be clustered in groups or patterns. In fact to the ancients the sky was filled with all kinds of figures which one can suppose made the sky seem more personal and familiar. These figures are called constellations (meaning "stars together").

Some star names:
Vega
Sirius
Aldebaran
Arcturus

Constellations
"Stars Together"

Many still bear the ancient names given to them and the names are still used by astronomers to identify stars and regions in the sky. One of the first tasks of an amateur astronomer is to become familiar with these ancient constellations for they are very helpful in learning to appreciate the night sky and in locating objects in the sky quickly and easily. Before you do the questions and problems on pages 21-24, read page 25, read one of the Sections and make observations of the sky.

Knowledge of constellations is important in astronomy

Problems

Before you do these problems read page 25 and Section I, or Section II or Section III whichever fits your time of star observation.

1. In which of the polar constellations would you expect to find each of the following stars?

Thuban ______________________

Megrez ______________________

Caph ______________________

Polaris ______________________

Phad ______________________

Kochab ______________________

Mizar ______________________

Merak ______________________

Dubhe ______________________

2. Where would you expect to find each of the following constellations [polar zone (P), between pole & ecliptic (P & E), ecliptic (E), or below ecliptic (BE)]? Fill in only the blanks for the Section you read.

Section I
- ________ Cassiopeia
- ________ Square of Pegasus
- ________ Aquila, the Eagle
- ________ Draco, the Dragon
- ________ Cygnus, the Swan
- ________ Lyra, the Lyre

Section II
- ________ Orion, the Hunter
- ________ Ursa Minor, the Little Bear
- ________ Taurus, the Bull
- ________ Auriga, the Charioteer
- ________ Gemini, the Twins
- ________ Canis Major, the Big Dog

Section III
- ________ Boötes, the Herdsman
- ________ Ursa Major, the Great Bear
- ________ Leo, the Lion
- ________ Virgo, the Virgin
- ________ Cassiopeia
- ________ Draco, the Dragon

3. In which constellation would you expect to find each of the following stars? (Complete only the blanks for the Section that you read.)

Section I
- ________________ Polaris
- ________________ Altair
- ________________ Deneb
- ________________ Vega

Section II

______________	Rigel
______________	Polaris
______________	Aldebaran
______________	Sirius
______________	Pollux
______________	Capella

Section III

______________	Regulus
______________	Polaris
______________	Spica
______________	Arcturus
______________	Antares

4. What is important about the line joining Polaris and Caph in the constellation Cassiopeia?

____

____

5. As you read one of the Sections of this lesson you did some observations of the sky.

   (a) At what time of the year did you make your observations? (Give the day and the month.) ______________

   (b) At what time of the day approximately? ______________

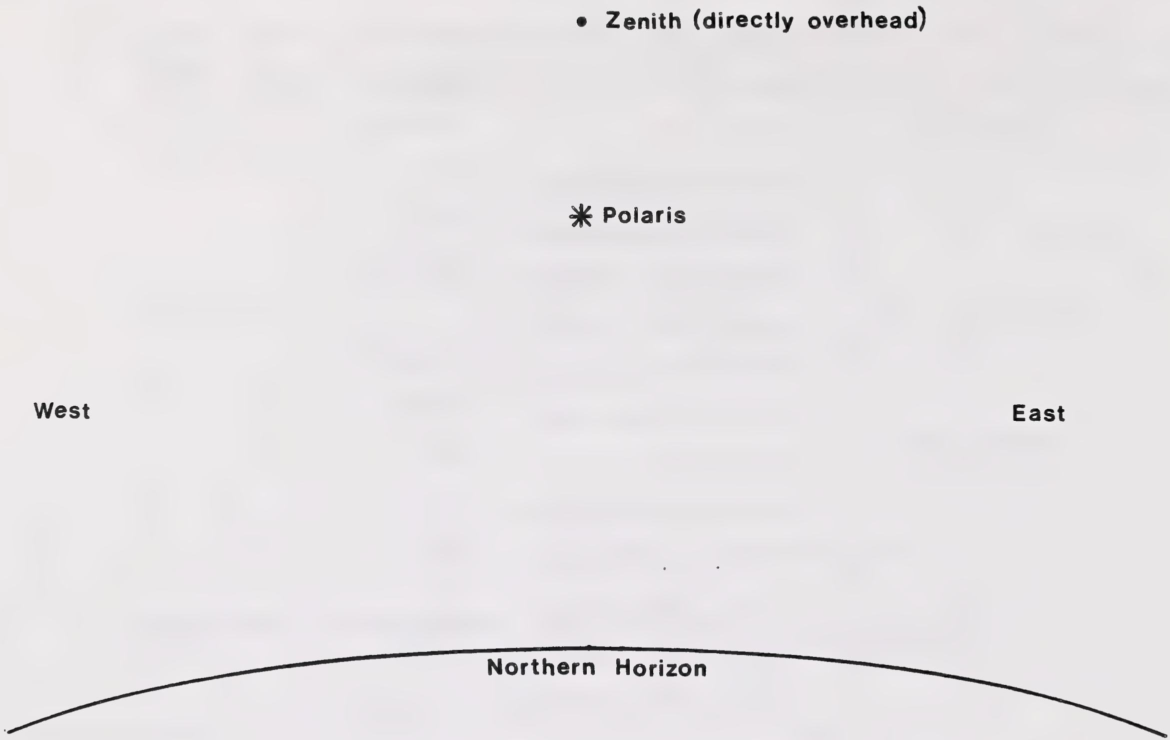
   (c) List by name the bright stars that you found without doubt in your observations.

   ____

   ____

   (d) On the following page locate the positions of the stars and constellations you observed. At the top of the page show the sky as it appeared to you <u>looking north</u>.

   If the moon is in the sky at the time of your observations, include it in your diagram showing its lighted shape as well as its position in the sky.



The Sky As It Appears to Me Looking North

Introduction to Sections I, II and III

Constellations of the Northern Hemisphere

We have already noted that the sun appears to move through the sky against the background of stars. This means that at different times of the year different stars are visible. Also because of the earth's rotation the evening sky is different from the morning sky.

To take this into account we will be dividing the sky into seasonal parts. We will also divide it into four zones for each season to more easily locate constellations. Use the table below to choose the section that fits your time of year. Study the section carefully, observing the sky as you do so. If the sky is not clear, go on to Lesson 11A, but come back to this lesson as soon as the sky becomes clear. Do the problems on pages 21 to 24 after you have finished studying the appropriate section.

Time of Year	Evening or Morning	Section
September, October, November	Evening (5:00 P.M. - 10:00 P.M.)	I
	Morning (5:00 A.M. - 7:00 A.M.)	II
December	Early Evening (4:30 P.M. - 9:00 P.M.)	I
	Late Evening (9:00 P.M. - 11:00 P.M.)	II
	Morning (6:00 A.M. - 8:00 A.M.)	III
January, February, March	Evening (6:00 P.M. - 11:00 P.M.)	II
	Morning (5:00 A.M. - 7:00 A.M.)	III
April, May, June	Evening (9:00 P.M. - 12:00 P.M. MDT)	III
End of July, August	Evening (11:00 P.M. - 12:00 P.M. MDT)	I

The following scheme is used to show the relative brightness of the stars:

☼ brighter than first magnitude

⌖ first magnitude

✳ second magnitude

✦ third magnitude

• fourth magnitude

Section I: Constellations of the Northern Hemisphere

Constellations of Evening (September, October, November)
Constellations of Late Evening (End of July, August)
Constellations of Early Evening (December)

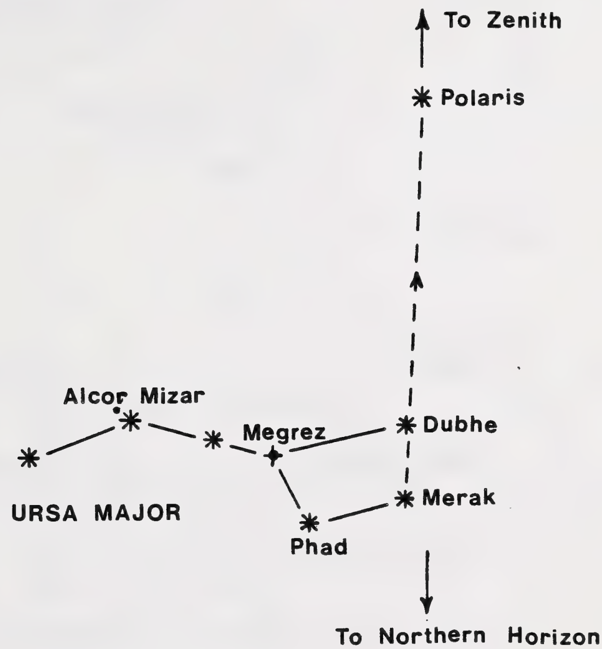
We will consider in this section the constellations as they appear about the middle of October at about 8:00 P.M. (MST) or 9:00 P.M. (MDT). In September the constellations shown will be farther east at the same time and in November they will be farther west.

1. The Polar Zone

In this zone the stars are visible at all times of the year. They never rise nor set but appear to move in a circle around the north star, Polaris.

The Circumpolar Whirl (A Time Exposure of the Stars Near the North Star).

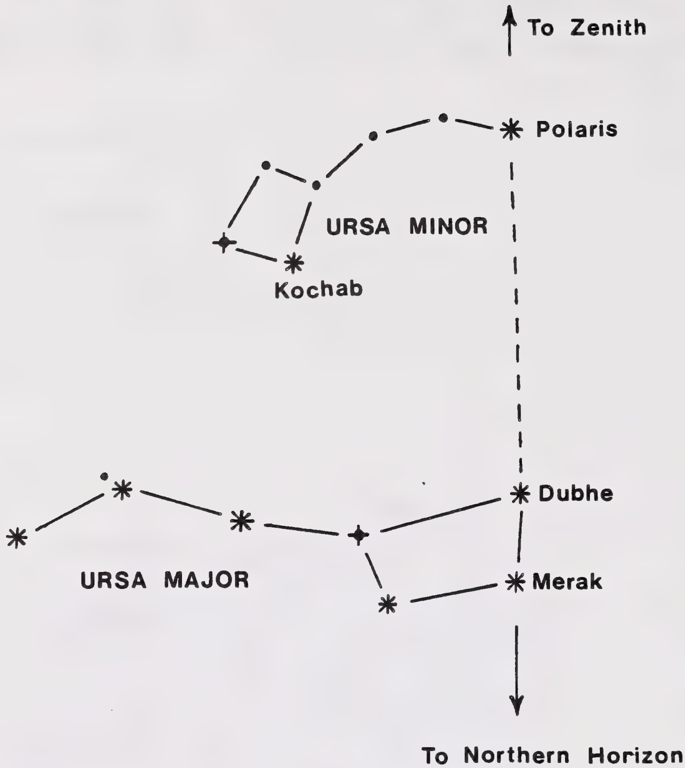
The most familiar constellation in this region is Ursa Major, part of which is called the Big Dipper. The Dipper has been known by various names throughout history — the Plough (England), the Wagon, the Seven Oxen.



The Big Dipper (Looking North) - October Evenings

Six months earlier in April the Big Dipper would appear almost directly overhead. It will be important to know the names of the stars shown because they will be used as pointers to help locate other stars and constellations. Note how Dubhe (Doob-hĕ) and Merak point to Polaris.

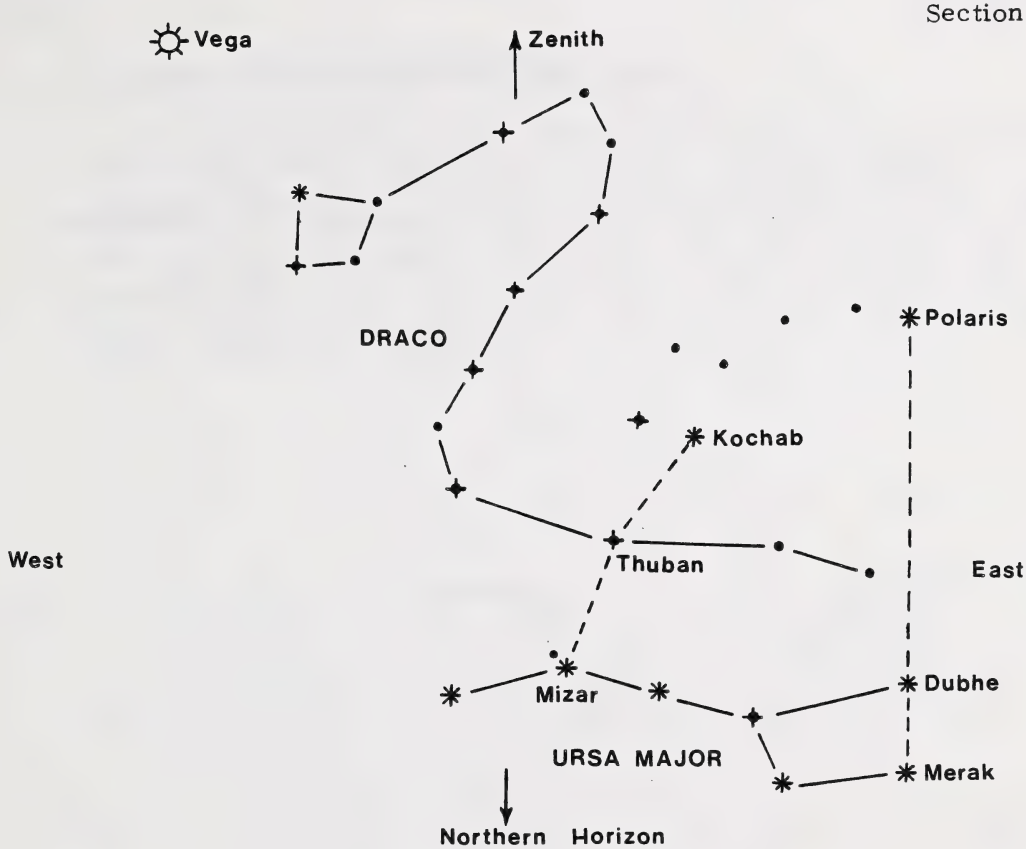
The second constellation in this area is considerably dimmer than the Big Dipper. It is the Little Dipper (officially known as Ursa Minor - the Little Bear). Polaris is at the end of its handle.



The Little Dipper (Looking North) - October Evenings

The second magnitude star on the lip of the Little Dipper is Kochab. Note that the other stars in the Little Dipper are much dimmer than Polaris, Kochab and the stars of the Big Dipper.

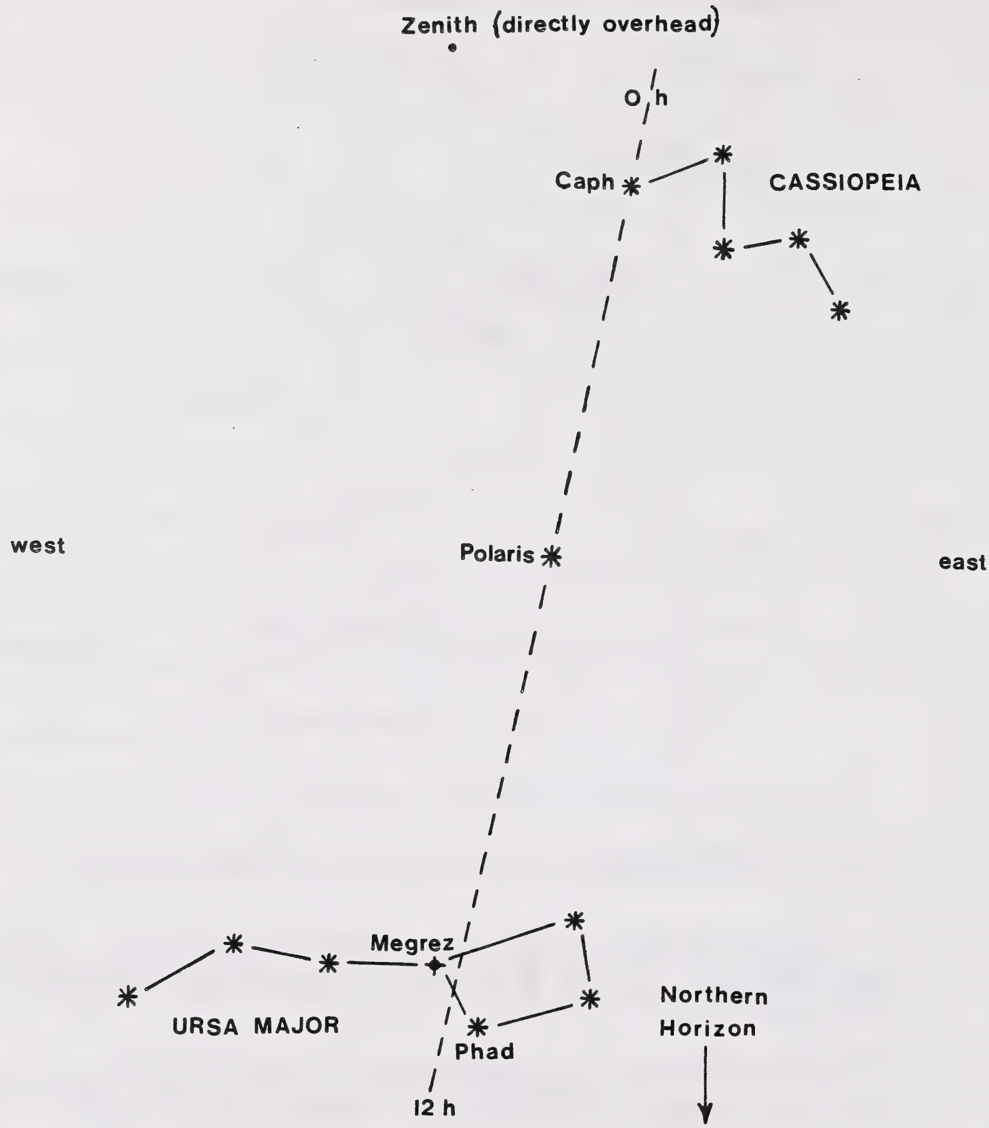
The third constellation in this area is a very long one, as its name suggests. It is Draco the Dragon.



Draco the Dragon (Looking North) - October Evenings

Note that Thuban lies about halfway between Mizar and Kochab. Note also that the head of Draco lies between Thuban and the bright star Vega.

The fourth and last constellation is, along with the Big Dipper, one of the easiest constellations to recognize in this area. First of all it lies directly across Polaris from the Big Dipper. Secondly it is in the shape of a huge W. It is the constellation Cassiopeia.

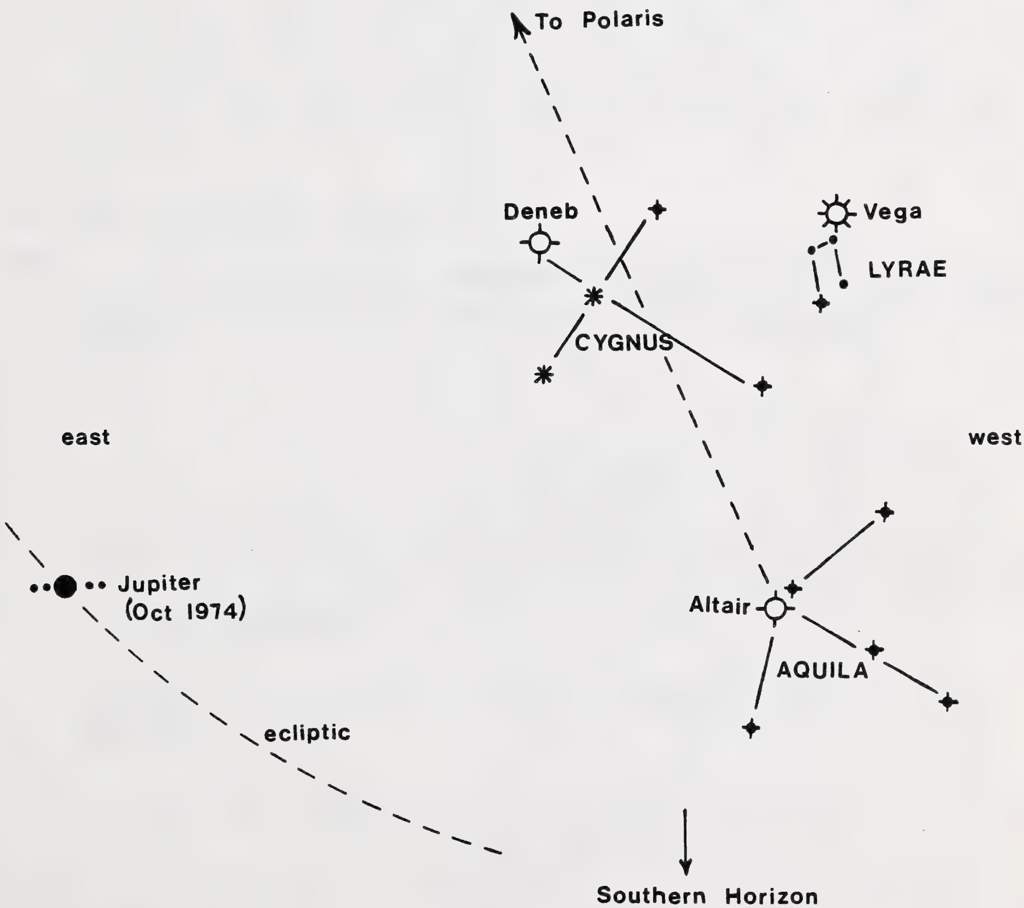


Cassiopeia (Looking North) - October Evenings

During October evenings Cassiopeia is high overhead and somewhat to the southeast of Polaris. The dotted line shown in the diagram is a very important one. This line from Polaris to Caph and on to the southern horizon is the 0 line from which astronomers measure east and west in the sky. It is something like 0° longitude on the earth's surface. The measurements taken east from this line are called <u>right ascension</u>. When the line is straight south it is 0 h star time.

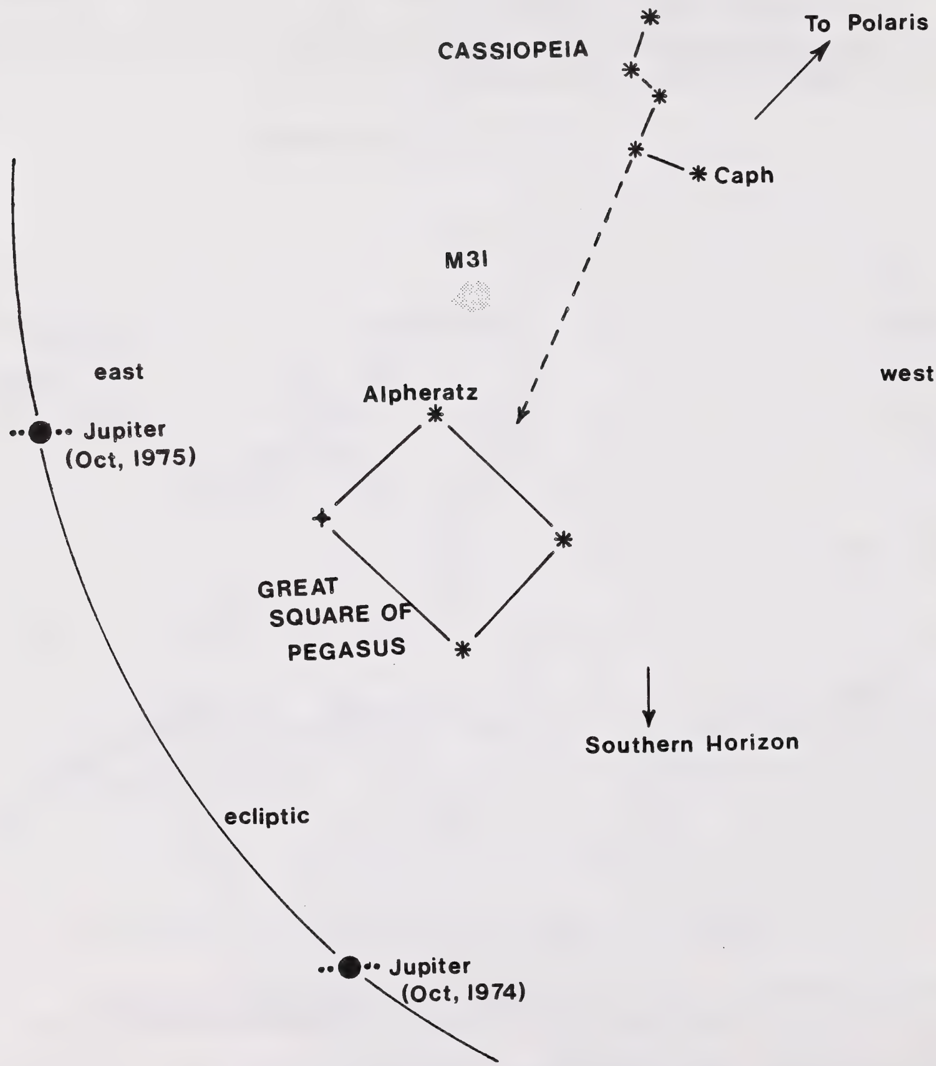
2. <u>The Zone Between Polaris and the Ecliptic</u>

The most outstanding stars in the sky at this time of the year are the three bright stars which form the "Summer Triangle." They are Vega, Deneb and Altair and in mid-October evenings they can be seen high in the southwest. The two stars nearest the north star are Vega and Deneb. Vega lies to the west of Deneb. The southern point of the triangle is formed by Altair. Vega is part of the constellation Lyrae (the Lyre), Deneb of Cygnus (the Swan) and Altair of Aquila (the Eagle).



Aquila, Cygnus and Lyrae (Looking South) - October Evenings

Another constellation which is quite well known but more difficult to find is Pegasus (the Flying Horse). The main part of the constellation is a large square formed by four stars. One way to find it is to draw a line through the two stars of Cassiopeia shown below and extend it southward.



Great Square of Pegasus (Looking South) - October Evenings

The scale on the diagram above is a bit deceiving. The square covers quite a large part of the sky — larger than is suggested by the diagram. Just above the square is M31, the Andromeda Galaxy. It appears as a fuzzy patch of light on a clear night and is the only galaxy in the northern hemisphere visible to the naked eye.

3. <u>The Ecliptic Zone</u>

The constellations on the ecliptic at this time of the year are quite dim. In addition the ecliptic is quite low in the south. Thus unless the sky is very clear and dark it is not easy to find them. This group of constellations include Capricornus (the Unicorn), Aquarius (the Water-Bearer), and Pisces (the Fish). If you wish to locate them refer to the Autumn star map at the end of this lesson.

4. <u>The Zone Below the Ecliptic</u>

Since the ecliptic is quite low in the sky at this time of year there are no significant constellations visible in this zone in early autumn.

In the autumn part of the sky there are three major bright stars — Altair, Deneb and Vega. If you see any other bright object in the sky, it is likely a planet. Attempt to show the position of such an object in your diagram on page 24.

There are many dimmer constellations that we have not identified. You may wish to find some of them with the aid of a star map or atlas.

Turn now to the problems on pages 21 to 24.

END OF SECTION I

Section II: Constellations of the Northern Hemisphere

Constellations of Late Evening (December)

Constellations of Evening (January, February, March)

Constellations of Morning (September, October, November)

In this section we will deal with constellations as they appear about the middle of February at about 20 00 h (8:00 P.M. MST) or in the middle of October at about 5 00 h or 6 00 h (5:00 or 6:00 A.M. MDT). In January at 20 00 h these constellations will be farther to the east than shown. In March they will be farther west.

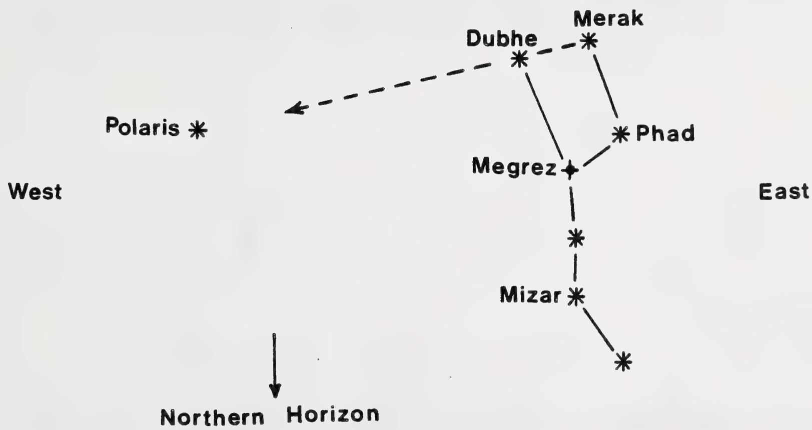
For this region of the sky the ecliptic is quite high in the sky.

1. The Polar Zone

In this zone the stars are visible at all times of the year. They never rise or set but appear to describe a circle around Polaris. The photograph below shows what happens when you expose a film to this zone for several hours.

The Circumpolar Whirl

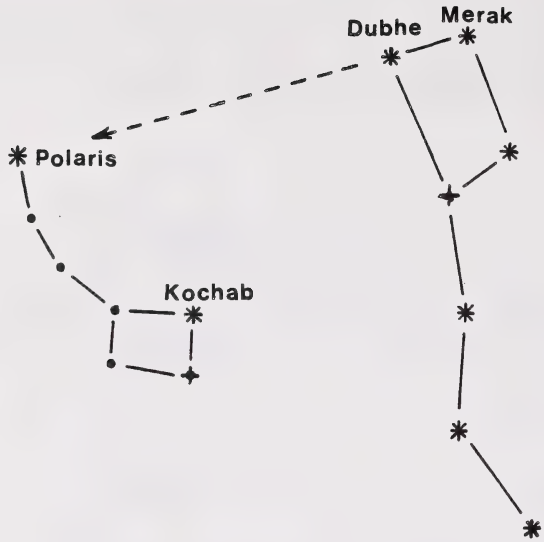
The most familiar constellation in this region is Ursa Major, the Great Bear. We more commonly call it the Big Dipper. It has been known by various names throughout history — the Plough (England), the Wagon and the Seven Oxen.



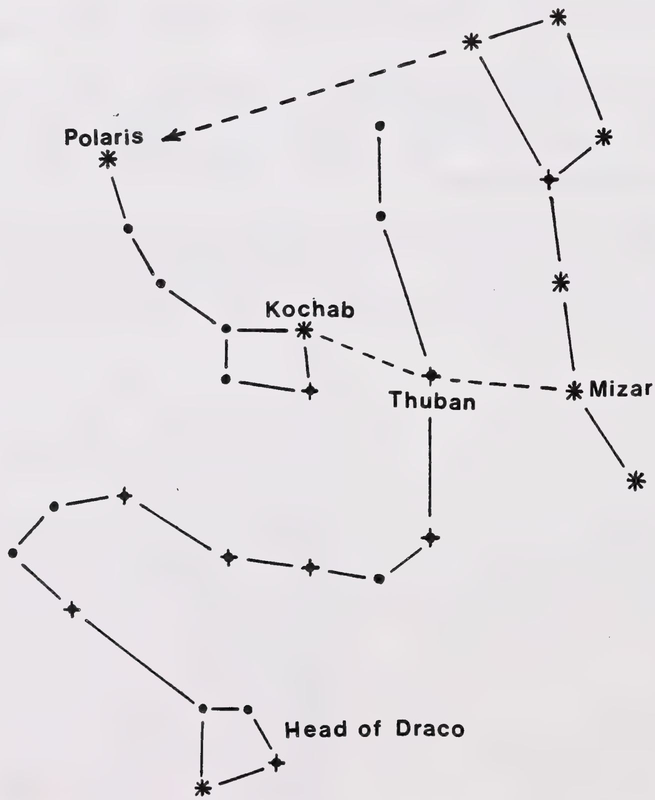
The Big Dipper (Looking North) - February Evenings

It is important to note the names of the stars of the Big Dipper. A line drawn between two of them (Merak and Dubhe) points to Polaris. We will find that other lines help us to locate nearby constellations.

The second constellation in this area is considerably dimmer than the Big Dipper. It is Ursa Minor, the Little Bear, more commonly called the Little Dipper. Polaris is at the end of its handle.



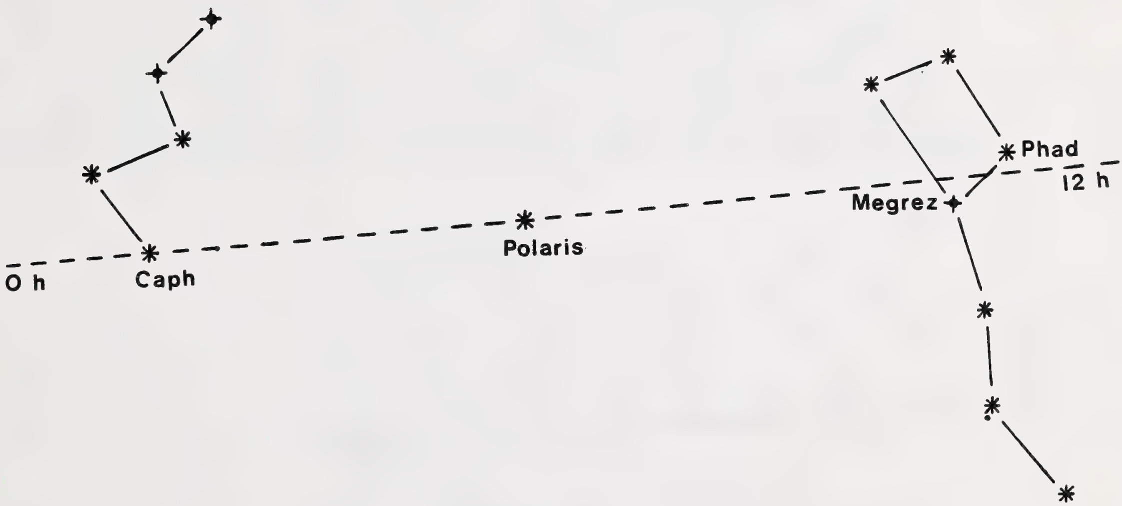
The Little Dipper (Looking North) - February Evenings



Draco the Dragon (Looking North) - February Evenings

Note that Thuban (a star in the Dragon's tail) lies about halfway between Kochab and Mizar. At this time of the year the head of the Dragon is near the northern horizon and so may not be highly visible.

The fourth constellation in this zone is about as bright as the Big Dipper and quite easy to recognize. It lies directly across Polaris from the Big Dipper and is shaped something like a huge W. It is Cassiopeia, "The Lady in the Chair."



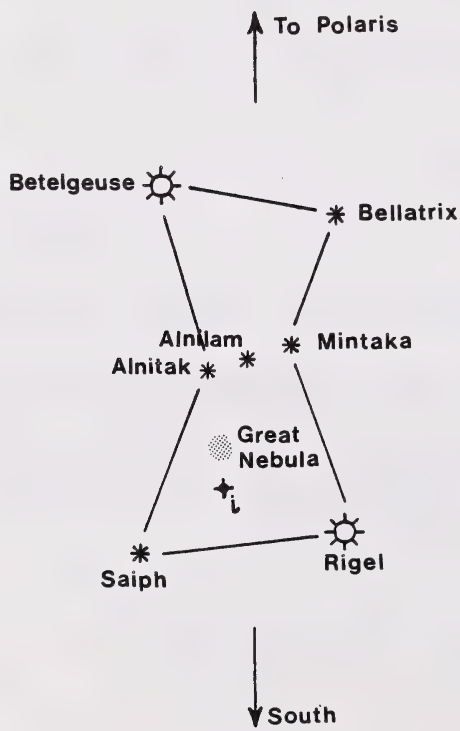
Cassiopeia (Looking North) - February Evenings

The line shown in the diagram joining Polaris and Caph is a very important one. It is the 0 line from which astronomers measure distances east and west in the sky. It is something like 0° longitude on the earth's surface. The measurements taken east from this line are called <u>right ascension</u>. When the line is straight south it is 0 h sidereal (star) time.

2. <u>The Zone Below the Ecliptic</u>

In the fall and winter seasons the ecliptic is quite high in the sky in the evenings. (This is the part of the sky that the sun occupies in summer.) In addition there are a number of very bright stars in this part of the sky. Not only this, but during the winter the stars are visible much longer each evening because the nights are long. Thus winter evenings provide excellent opportunity for observing the night sky.

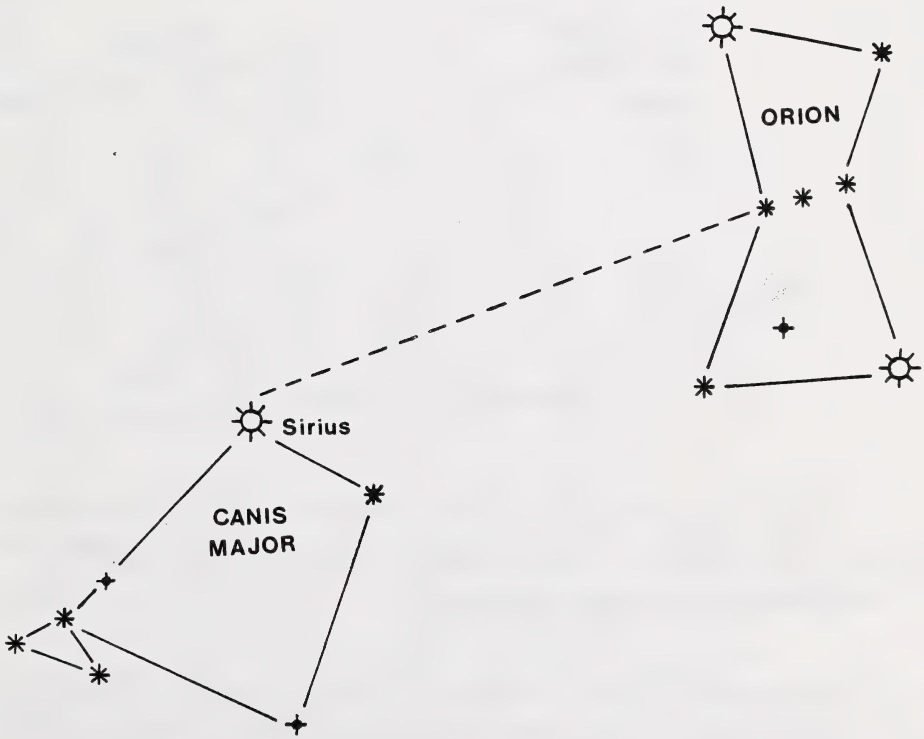
We begin with what is probably the most outstanding constellation in the sky, Orion, the Hunter. Four of the bright stars in this constellation form a quadrilateral (four-sided figure). Two of these four corner stars are very bright — Betelgeuse (bĕtél-jooz) at the upper left and Rigel (rī-jel) at the lower right. The other five major stars in the constellation are of second magnitude or brighter.



Orion the Hunter (Looking South) - February Evenings

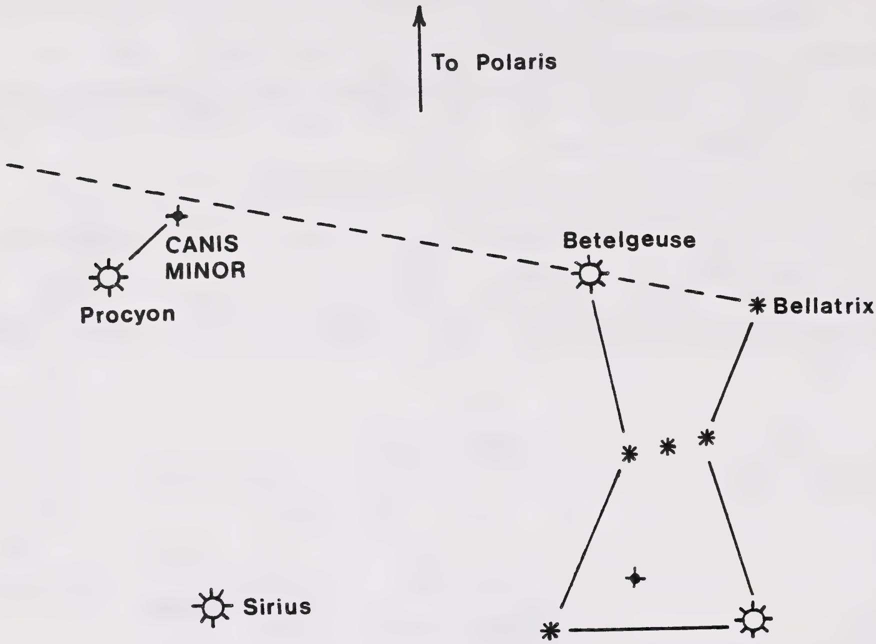
Betelgeuse and Bellatrix form the two shoulders of the Hunter, while Alnitak, Alnilam and Mintaka form his belt. A sword hangs down from Alnitak through the Great Nebula to ι. Orion can be seen from as early as the end of October (midnight) to as late as the end of March (just after sunset). Thus it dominates the sky during winter.

To the southeast of Orion we find the brightest star in the sky, Sirius in Canis Major (the Big Dog). Follow a line through the belt of Orion to Sirius.



Sirius in Canis Major (Looking South-East) - February Evenings

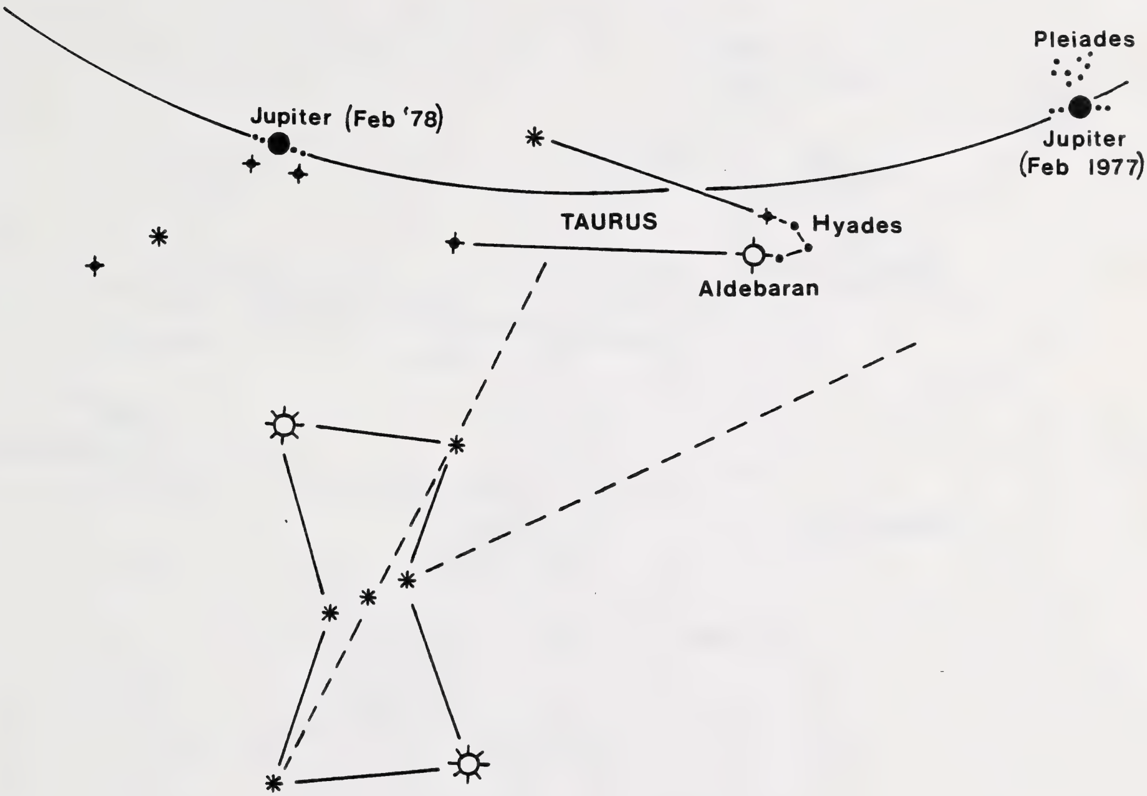
Just to the east of Orion is another bright star in Canis Minor (the Little Dog) called Procyon (prō´sĭ-ŏn). Follow a line eastward through Bellatrix and Betelgeuse.



Canis Minor and Procyon (Looking South) - February Evenings.

3. <u>The Ecliptic Zone (Zodiac)</u>

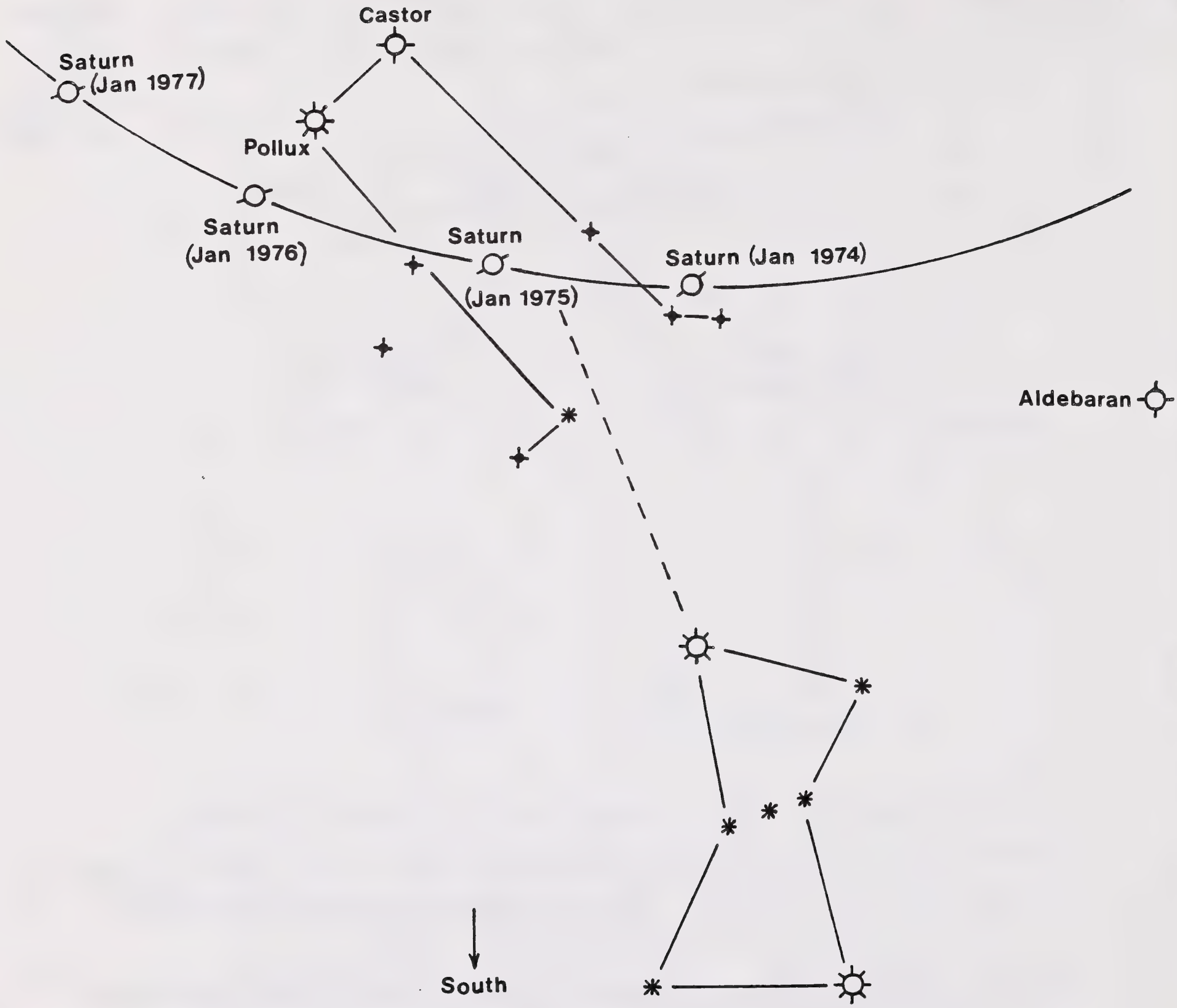
The ecliptic lies just above Orion. The sun is in this part of the sky in June. Near the ecliptic there are a number of bright stars and other interesting objects. One of them is the bright star, Aldebaran, the eye of Taurus, the Bull.



Aldebaran in Taurus (Looking South) - February Evenings

To the right and above Aldebaran there is the famous cluster of dim stars called the Pleiades (Plee yuh deez). The cluster of stars near Aldebaran is called the Hyades.

The next zodiac constellation, Gemini the Twins, contains the bright twin stars Castor and Pollux. They lie above Orion and to the left. A line joining Rigel and Betelgeuse points roughly in the direction of Gemini.

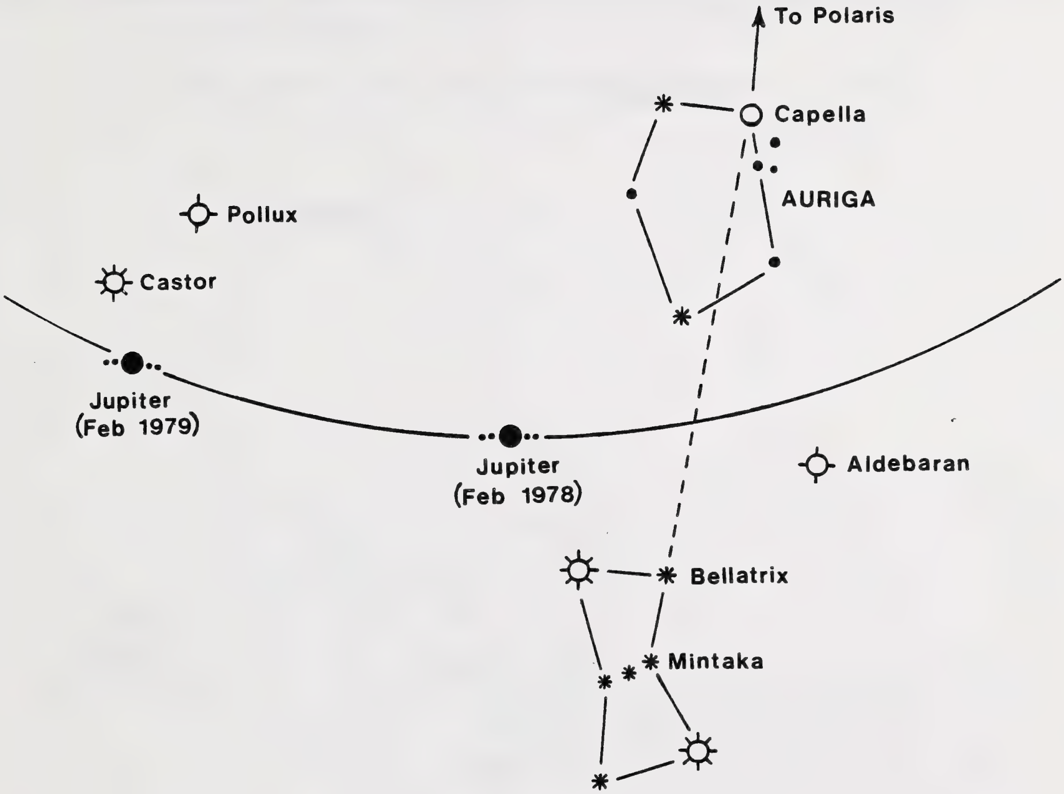


Gemini, the Twins (Looking South) - February Evenings

Of the twin stars Castor and Pollux, Castor is the closer to the pole star. The next zodiac constellation to the east of Gemini is Cancer. It is quite dim and difficult to find.

4. The Zone Above the Ecliptic

There are two noteworthy constellations in this zone. One of them, Auriga the Charioteer, is just above the ecliptic and contains the bright star, Capella. A line drawn between Mintaka and Bellatrix points to Capella.

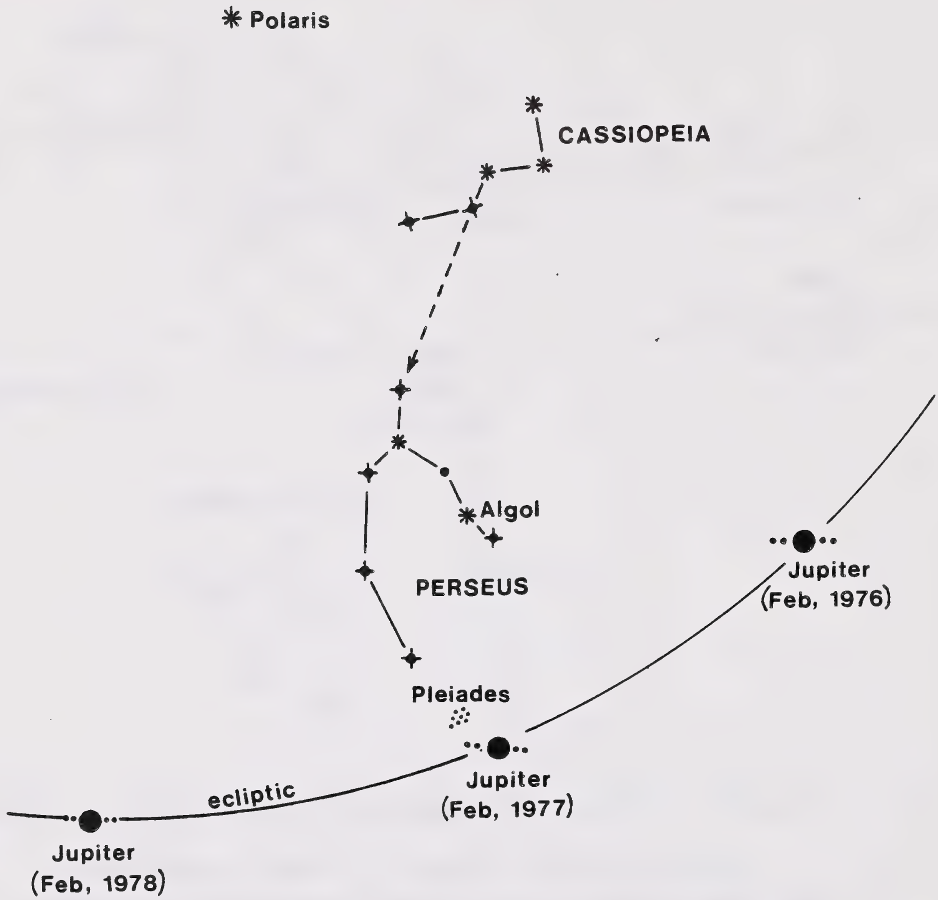


Capella in Auriga the Charioteer (Looking South) - February Evenings

Capella is nearly directly overhead when Orion is in this position. Another way to find Capella is to note that it is about half way between Orion and Polaris.

There is another constellation in this part of the sky which is noteworthy. It does not have any very bright stars but it has an interesting star, Algol, which changes its brightness every several days. Algol is actually a system of two stars rotating about each other. Every day or so one of them eclipses the other causing a change in brightness.

Algol is in Perseus which lies just to the north of the Pleiades toward Polaris. One way to find it is to draw a line between two stars in Cassiopeia as shown below.



Perseus, Son of Jupiter and Algol (Looking South) - February Evenings.

If you are able to observe Algol several nights in succession you may see it change in brightness.

It is worth noting that the part of the sky that we have been studying in this section has no fewer than eight bright stars — Betelgeuse, Rigel, Sirius, Procyon, Aldebaran, Castor, Pollux and Capella. Can you locate them all? If you look to the east you may also be able to see Regulus in Leo the Lion which we will introduce in the next section. If there are any other bright objects in the sky they are likely planets.

There are many of the dimmer constellations that we have not identified. You may wish to find some of them with the help of a star map or atlas.

Turn now to the set of problems on pages 21 to 24.

END OF SECTION II

Section III: Constellations of the Northern Hemisphere

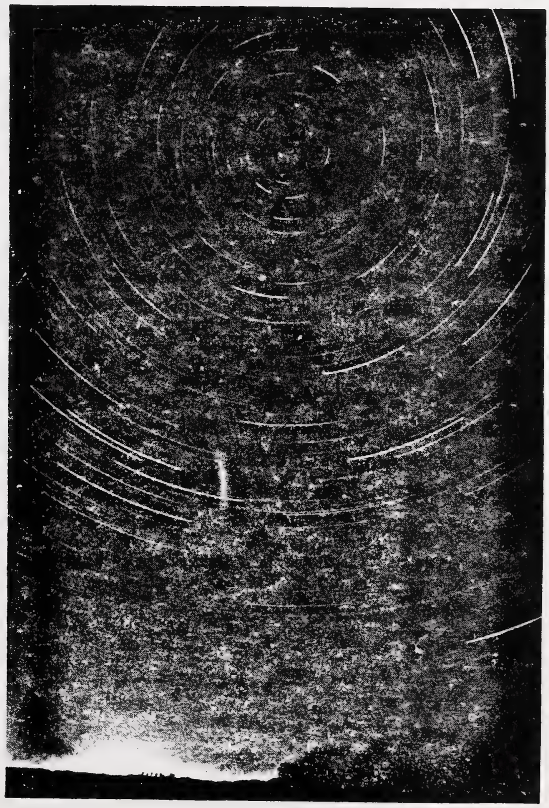
Constellations of Evening (April, May, June)

Constellations of Morning (November, December, January)

We will consider in this section the constellations as they appear about the middle of May at 22 00 h (10:00 P.M. MDT). In April the constellations shown will be further east at the same time and in June further west. Observation at this time of the year must be quite late because the sun sets at about 21 30 h (9:30 P.M. MDT).

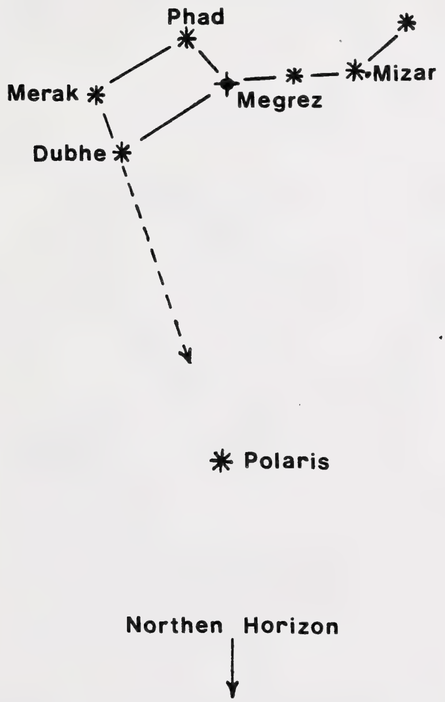
1. The Polar Zone

In this zone the stars are visible at all times of the year. They never rise nor set but appear to move in circles around the pole star, Polaris. The photograph below shows what happens when you time expose film in a camera pointed at the pole star for a period of several hours.



The Circumpolar Whirl

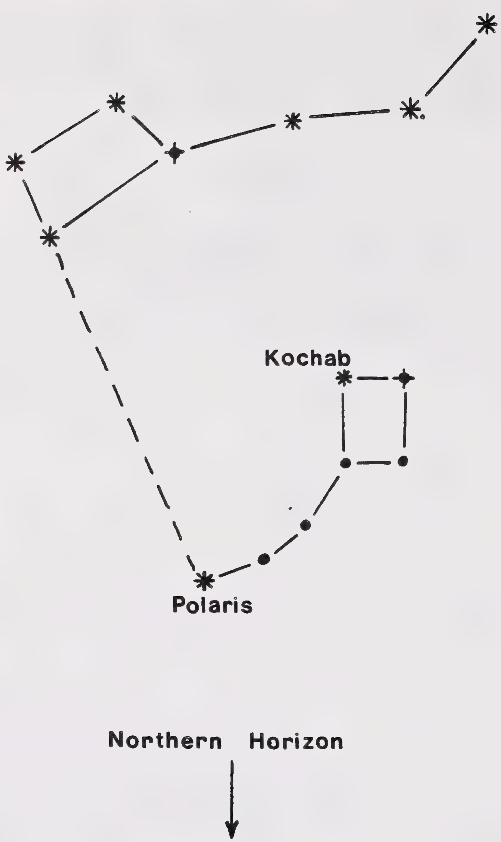
The most familiar constellation in this region is Ursa Major, the Great Bear. More commonly it is called the Big Dipper. It has been known by various names throughout history – the Plough (England), the Wagon, the Seven Oxen.



The Big Dipper (Looking North) - May Evenings

Note that at this time the Big Dipper is almost directly overhead. It is important to note the names of the stars in the Big Dipper. For example, the two "pointers" Merak and Dubhe (Doob he) direct us to Polaris. Later we will use other stars in the Dipper to help locate nearby constellations. Note that the star in the bend of the Dipper's handle is a double star. The dimmer star is of fourth magnitude and is called Alcor.

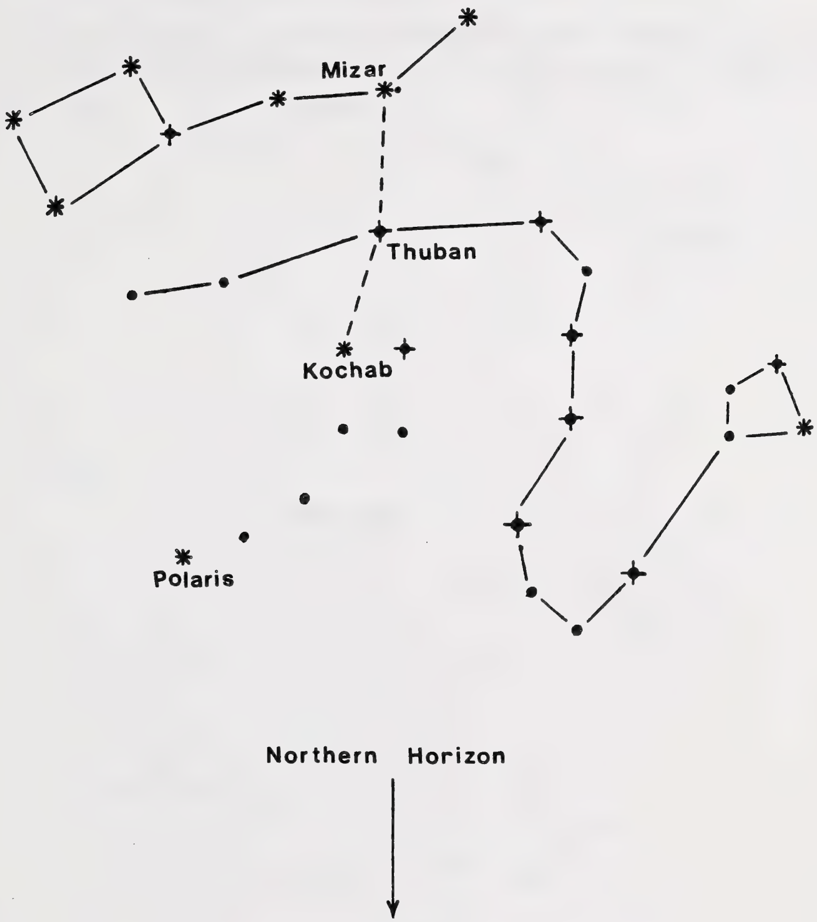
The second constellation in this zone is considerably dimmer than the Big Dipper. It is Ursa Minor, the Little Bear, also called the Little Dipper. Polaris is at the end of its handle.



The Little Dipper (Looking North) - May Evenings

The second magnitude star on the "lip" of the Little Dipper is Kochab. The other stars in this constellation are of fourth magnitude or less.

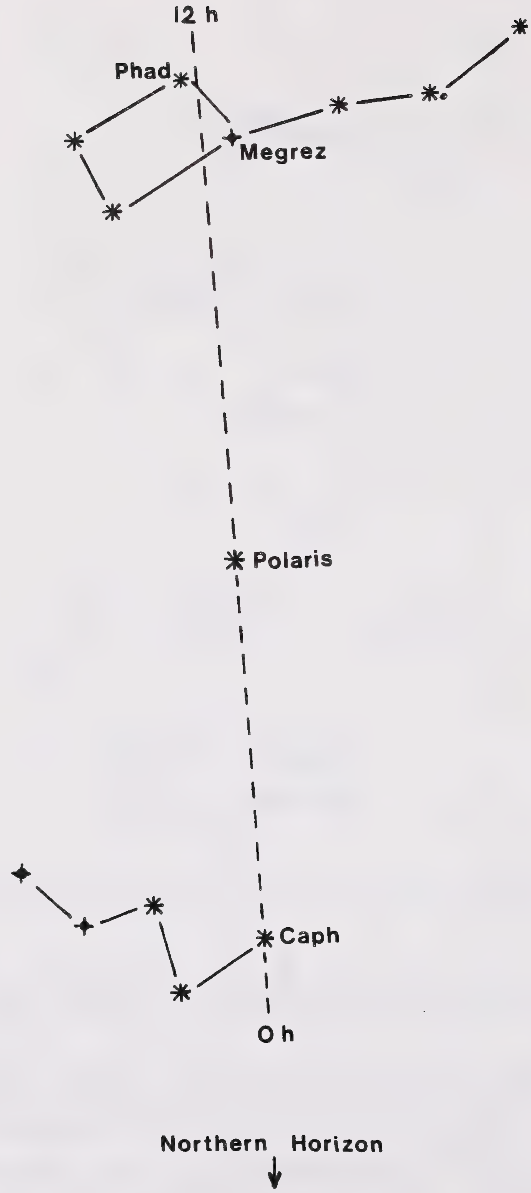
The third constellation in this area of the sky is a long one as its name suggests. It is Draco, the Dragon.



Draco the Dragon (Looking North) - May Evenings

Note that Thuban (a star in the Dragon's tail) lies about halfway between Kochab and Mizar in the Big Dipper.

So far all the constellations we have examined have been high overhead. The next constellation is lower in the north and fairly bright and easy to recognize. It lies directly across Polaris from the Big Dipper and is shaped something like a big W or M depending on how you look at it. It is Cassiopeia.

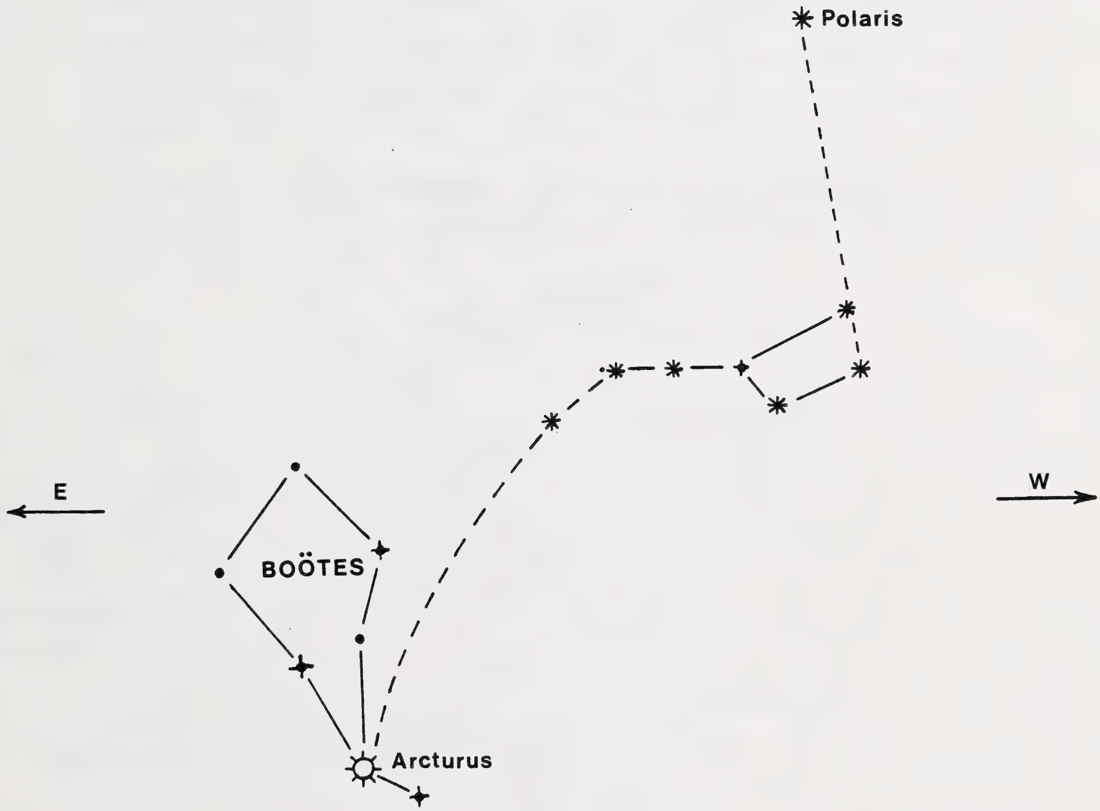


Cassiopeia (Looking North) - May Evenings

The line shown in the diagram joining Polaris and Caph is quite important. It is the 0 line from which astronomers measure distances east and west in the sky. It is something like 0° longitude on the earth's surface. The measurements east from this line are called <u>right ascension</u>. They are usually given in units of hours, minutes and seconds. When this line is straight south of you it is 0 h star time.

2. <u>The Zone Between the Ecliptic and Polaris</u>

If you follow the curve of the Big Dipper's handle you soon come to the bright star Arcturus in the constellation Boötes (bō ō tēz) the Herdsman.

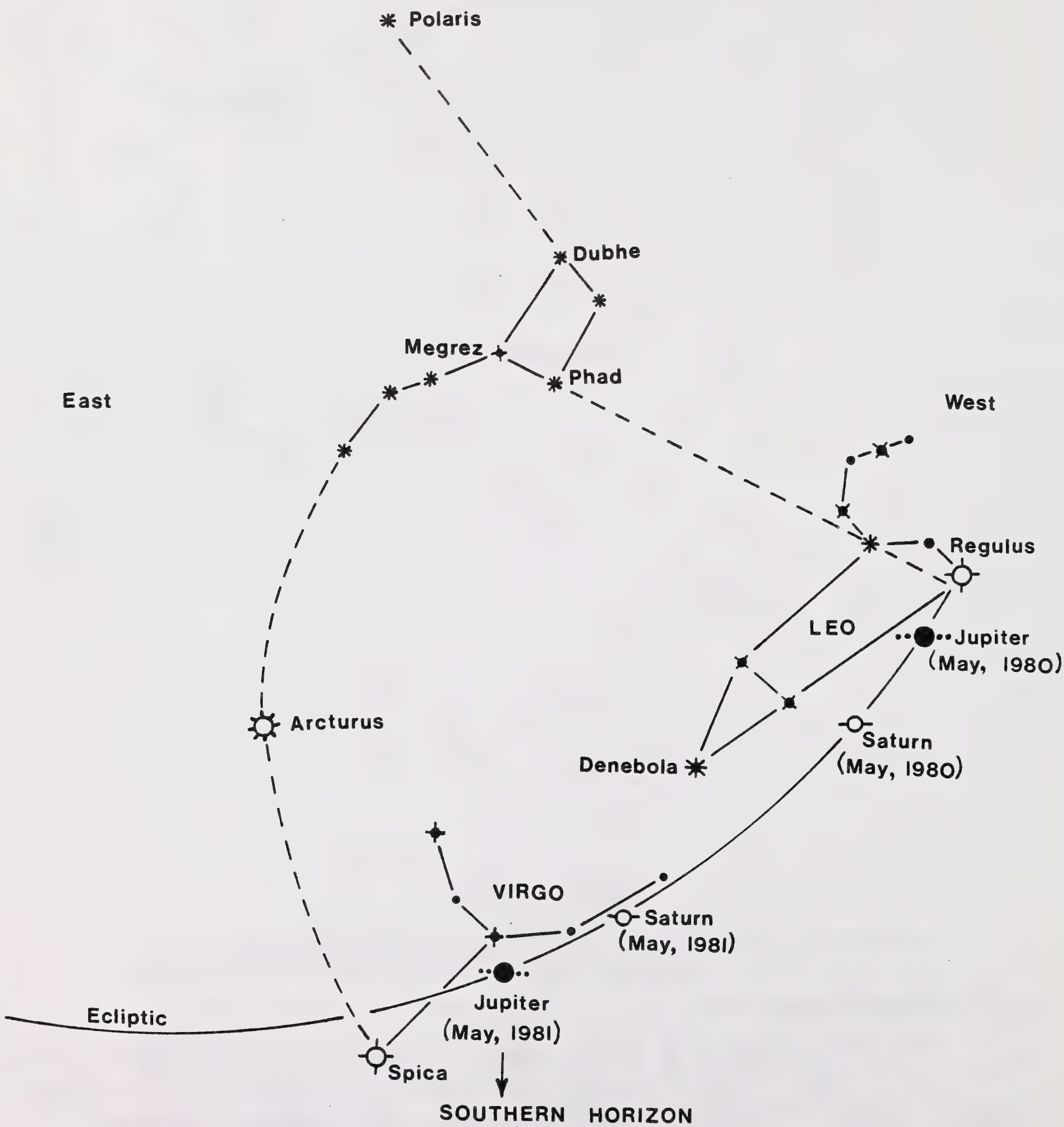


Boötes and Arcturus (Looking South) - May Evenings

3. <u>The Ecliptic Zone</u>

In this region of the sky there are two bright stars which are very nearly on the ecliptic. The first one can be found by continuing to follow the curve of the Big Dipper's handle beyond Arcturus.

The bright star you come to is Spica in the constellation Virgo. The other bright star is Regulus. It can be found by drawing a line through Megrez and Phad in the Big Dipper and following it south. Regulus is in the constellation Leo, the Lion. It is one of the brighter constellations on the ecliptic.



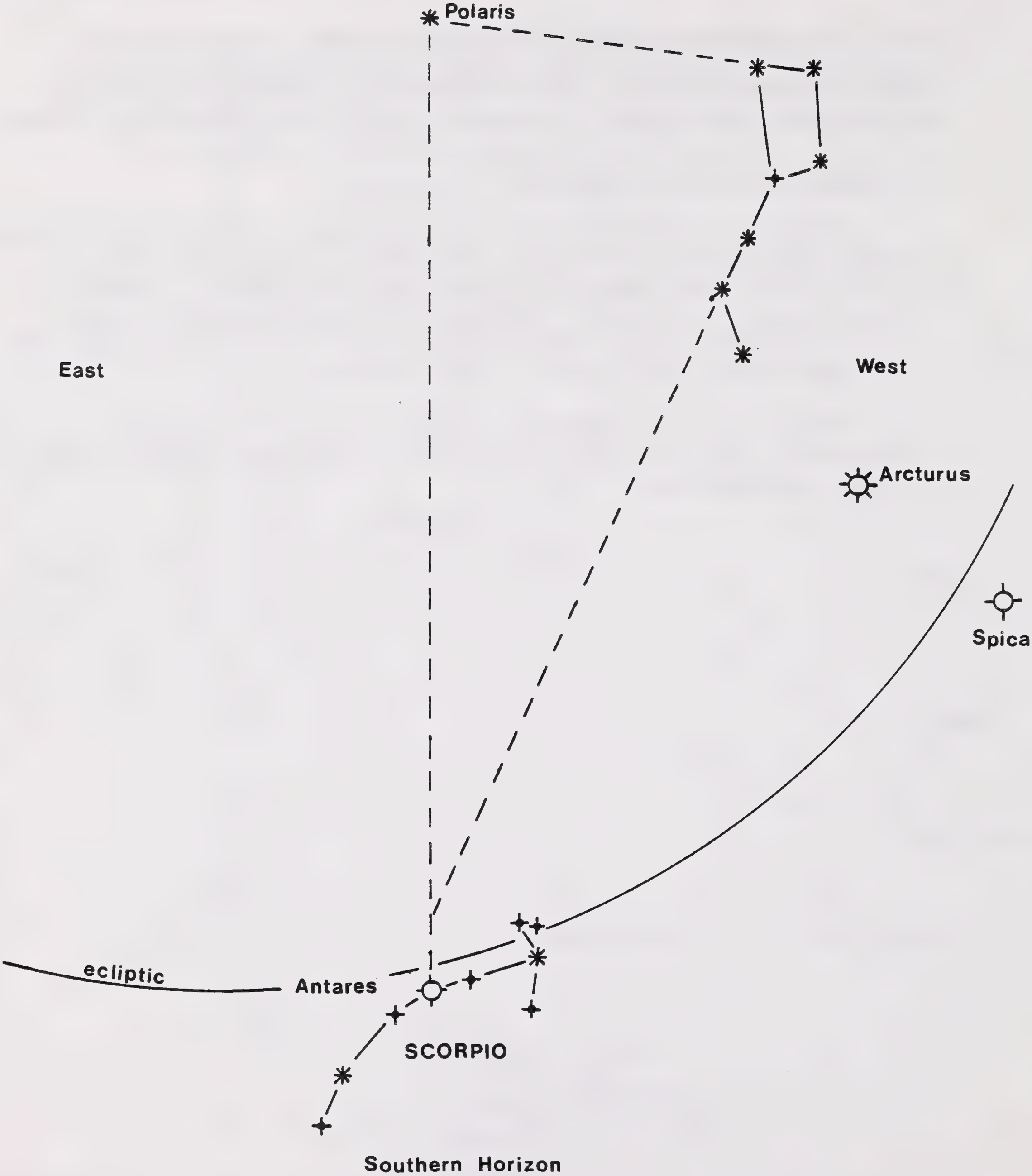
Spica in Virgo and Regulus in Leo (Looking South) - May Evenings

Note how close Regulus is to the ecliptic. The only other constellations on the ecliptic visible at this time are Cancer and Libra, both quite dim. Gemini located in the west or northwest should also be visible. You may be able to find Castor and Pollux.

4. <u>The Zone Below the Ecliptic</u>

Since the ecliptic is quite low in the south very few constellations below the ecliptic are visible. You may be able to see Procyon below Castor and Pollux in the west just after sunset. Antares in the Scorpio may also be visible very low in the south at about 24 00 h (12:00 midnight MDT) around June 15. You could also see it about 6 00 h (6:00 A.M.) in late February.

There are many dimmer constellations that we have not identified. You may wish to refer to a star map or atlas to find these constellations.

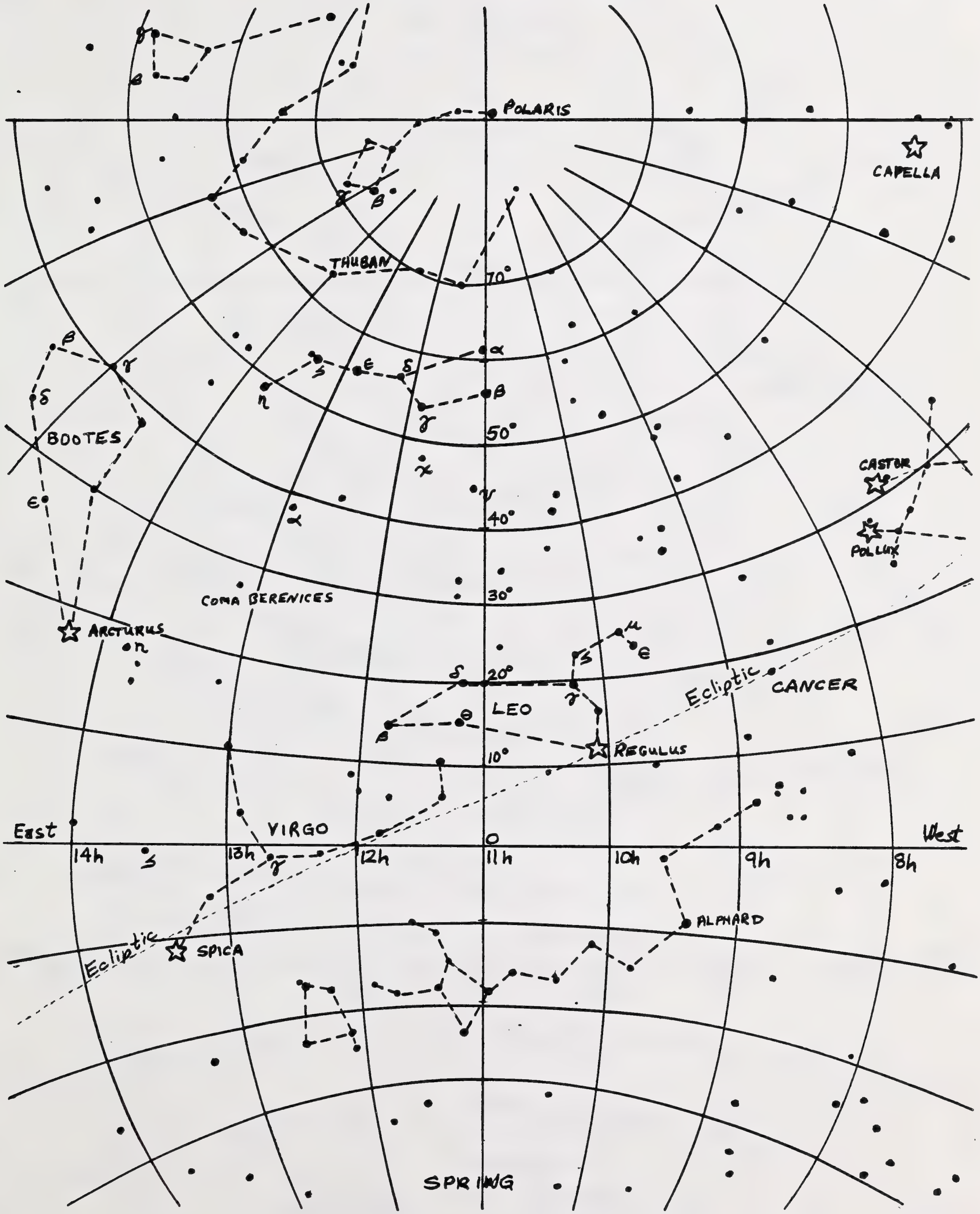


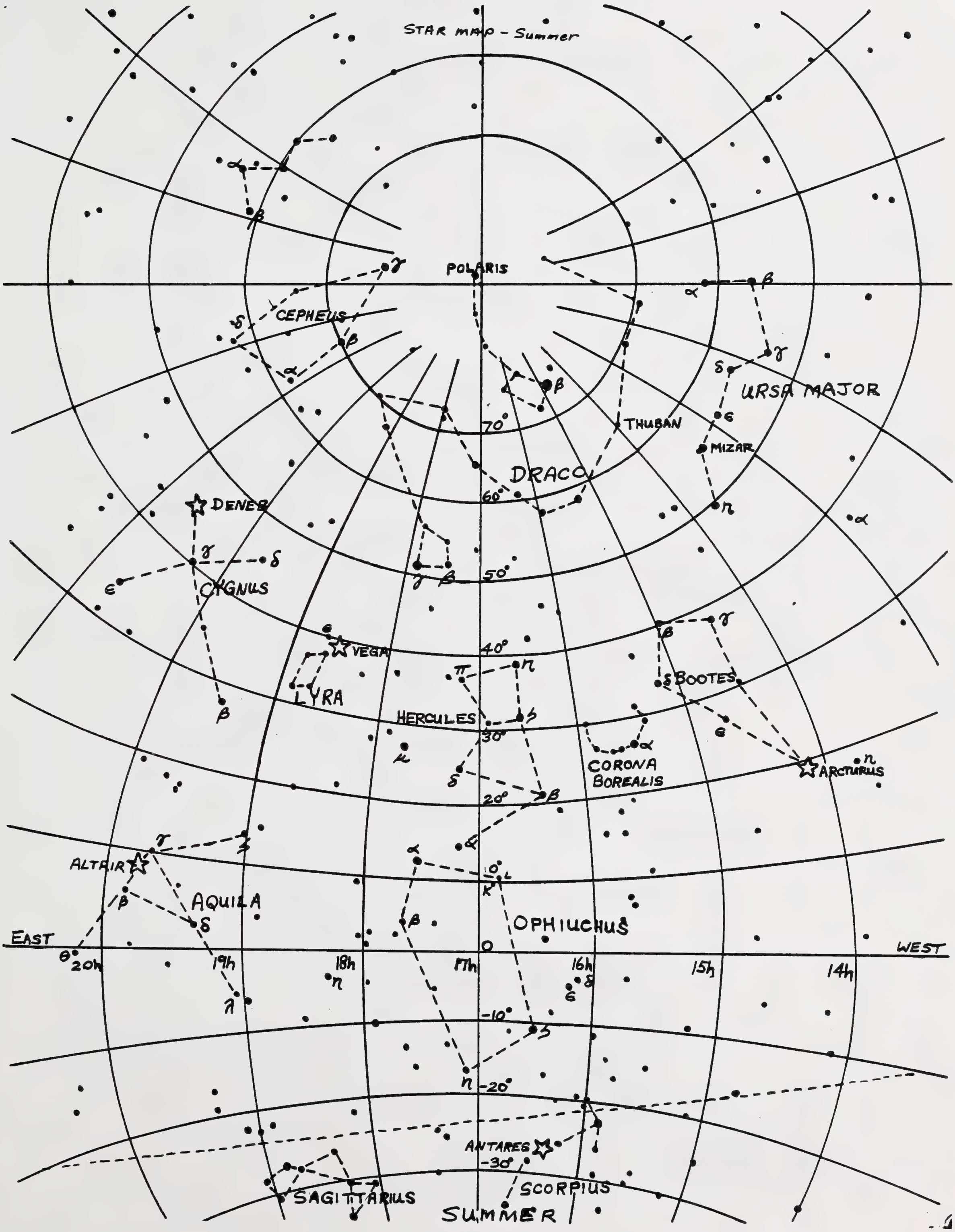
Antares in Scorpio (Looking South) - Middle of June about 12:00 midnight MDT.

Turn now to the set of problems on pages 21 to 24.

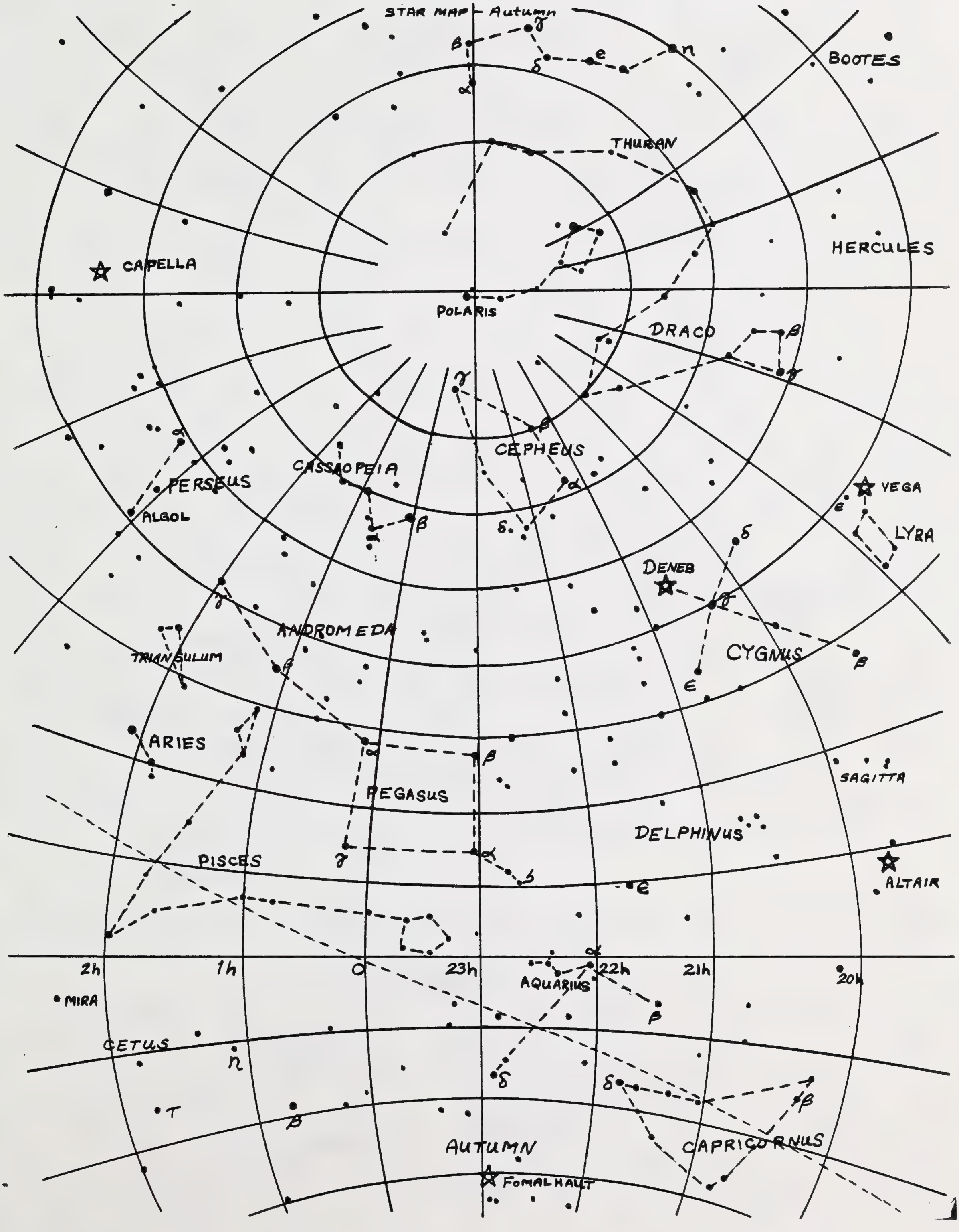
END OF SECTION III

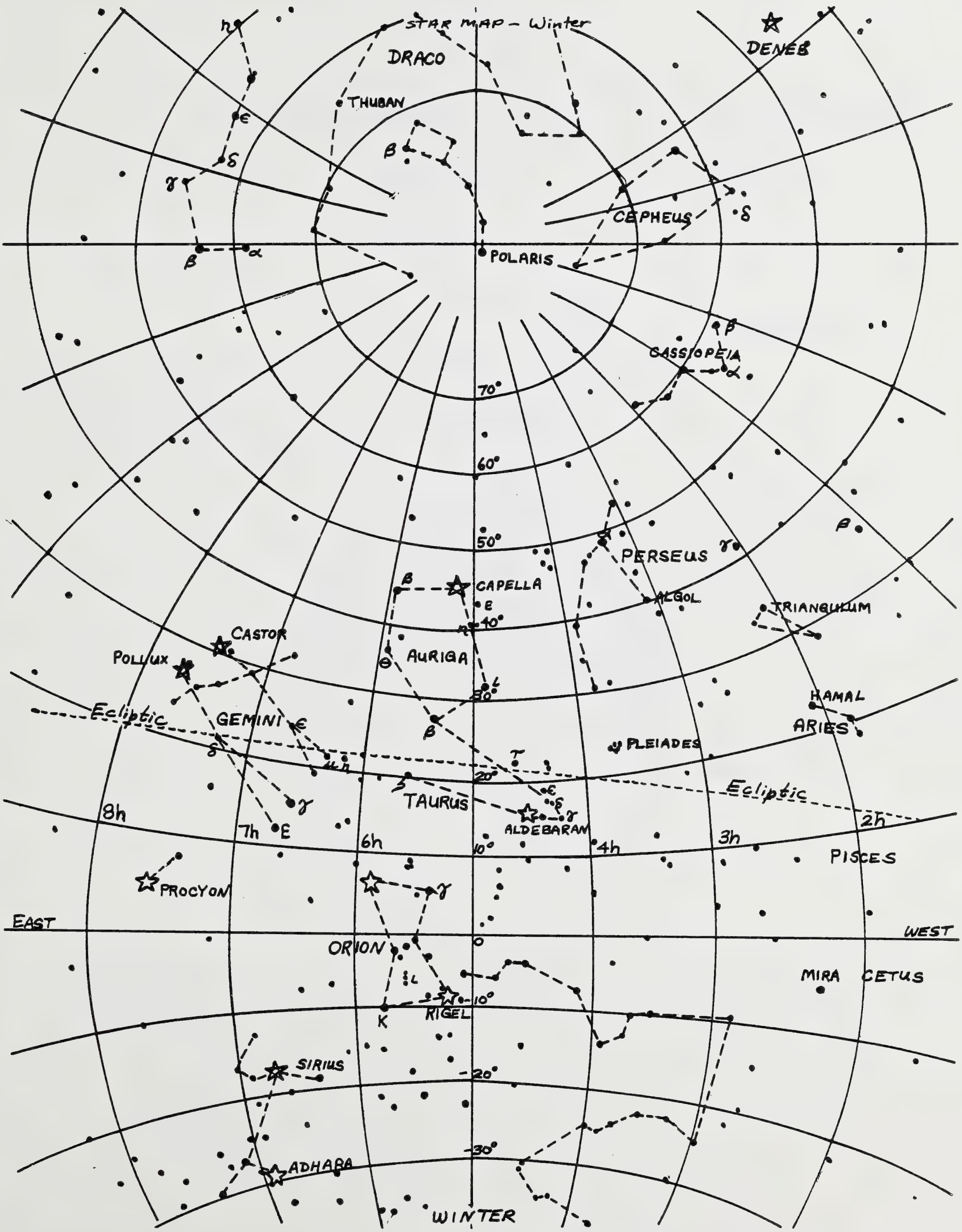
STAR MAP – Spring





STAR MAP - Summer
POLARIS
CEPHEUS
URSA MAJOR
THUBAN
MIZAR
DRACO
DENEB
CYGNUS
VEGA
LYRA
HERCULES
BOOTES
CORONA BOREALIS
ARCTURUS
ALTAIR
AQUILA
OPHIUCHUS
EAST
WEST
20h
19h
18h
17h
16h
15h
14h
70°
60°
50°
40°
30°
20°
10°
0
-10°
-20°
-30°
ANTARES
SAGITTARIUS
SCORPIUS
SUMMER


STAR MAP - Autumn
BOOTES
THUBAN
HERCULES
CAPELLA
POLARIS
DRACO
CEPHEUS
CASSIOPEIA
PERSEUS
ALGOL
VEGA
LYRA
DENEB
ANDROMEDA
TRIANGULUM
CYGNUS
ARIES
PEGASUS
SAGITTA
DELPHINUS
PISCES
ALTAIR
2h
1h
0
23h
22h
21h
20h
AQUARIUS
MIRA
CETUS
AUTUMN
CAPRICORNUS
FOMALHAUT



STAR MAP - Winter
DRACO
THUBAN
DENEB
CEPHEUS
POLARIS
CASSIOPEIA
70°
60°
50°
PERSEUS
CAPELLA
ALGOL
TRIANGULUM
CASTOR
POLLUX
AURIGA
40°
30°
GEMINI
HAMAL
ARIES
Ecliptic
PLEIADES
20°
TAURUS
ALDEBARAN
8h
7h
6h
4h
3h
2h
10°
PISCES
PROCYON
EAST
WEST
ORION
0
MIRA
CETUS
RIGEL
-10°
SIRIUS
-20°
-30°
ADHARA
WINTER

LESSON RECORD FORM

1260 Physics 10
Elective A
Revised 10/90

FOR STUDENT USE ONLY

Date Lesson Submitted ____________________

Time Spent on Lesson ____________________

(If label is missing or incorrect)

File Number ____________________

Lesson Number ____________

FOR SCHOOL USE ONLY

Assigned Teacher: ________

Lesson Grading: ______

Additional Grading E/R/P Code: ______

Mark: ________

Graded by: ________

Assignment Code: _____

Date Lesson Received: ____________________

Lesson Recorded _____

Student's Questions and Comments

Apply Lesson Label Here

Name ____________

Address ____________

Postal Code ____________

Please verify that preprinted label is for correct course and lesson.

Teacher's Comments:

____
Correspondence Teacher

St. Serv. 21-89

ALBERTA CORRESPONDENCE SCHOOL

MAILING INSTRUCTIONS FOR CORRESPONDENCE LESSONS

1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
(5) This mailing sheet is placed on the lesson.

2. POSTAGE REGULATIONS

Do **not** enclose letters with lessons.

Send all letters in a separate envelope.

3. POSTAGE RATES

First Class

Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.

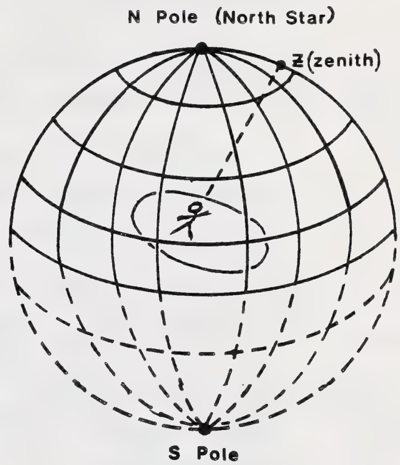
Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

MOTION IN THE HEAVENS

Motion in the Heavens - A Model

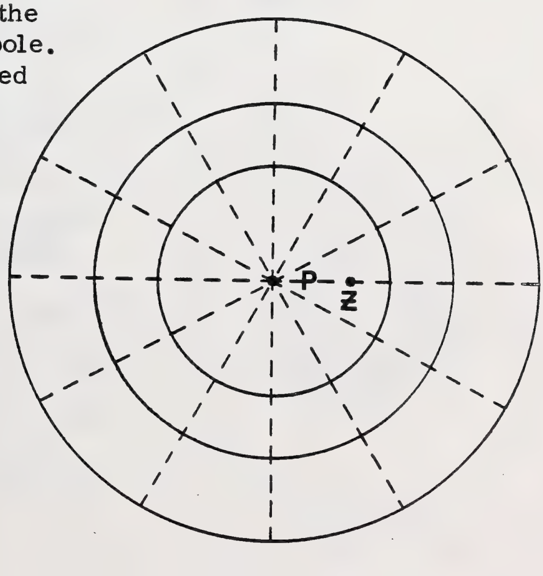
One of the oldest astronomical instruments is the astrolabe. It is really both a measuring instrument and an analog computer. The astrolabe was designed by the geometers of ancient Greece and made into a practical instrument for navigation by the Arabs. It was used for many hundreds of years for this purpose. Old astrolabes were made of carved or etched metals. We will use materials like plastic and plywood or cardboard to construct a simple astrolabe.



Before we do that it is important to understand the construction and geometrical principles of an astrolabe.

Imagine the sky as a hollow globe, or a hollow ball. Inside this globe at the centre is the earth. Imagine the earth to be shaped like a small flat disc, not the way it is but the way it appears to us as we stand on its surface. Imagine that the sky has lines of latitude and longitude like a globe of the earth and that the lines of longitude start at the North Star (the point around which the sky seems to turn).

Now suppose we could press that globe down into a flat surface so that all the longitude lines would still come together at the north pole but spread out at the south pole. We would then have something that looked like this:



The centre of the circle is the north pole occupied by the north star. The inner circle represents the circle that the sun follows on June 21 when it is highest in the sky. The middle circle represents the path of the sun on September 23 or March 21, when it is at the equinoxes. The outer circle represents the path of the sun in the sky on December 21 when it is lowest in the sky.

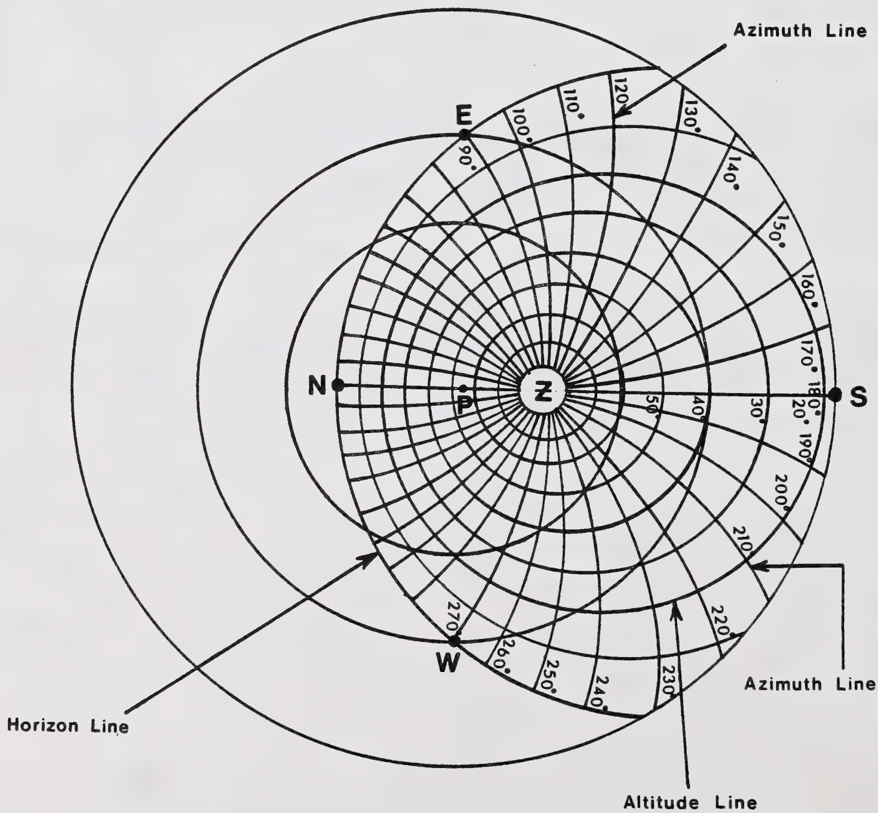
To measure distances in the sky from the earth we use degrees from north clockwise. This is called azimuth. We also use altitude above the horizon in degrees. Thus if a star is straight south its azimuth is 180°. If it is halfway up in the sky its altitude is 45°. The point directly overhead (altitude 90°) is called the zenith. It is shown as Z in the diagram. We can now add azimuth and altitude lines to our diagram. They look something like this:

Tropic of Cancer - path of the sun in the sky on June 21.

Tropic of Capricorn - path of the sun in the sky on Dec. 21.

Azimuth - degrees clockwise from north

Altitude - degrees above the horizon



The outermost circle (**ENW**) represents the horizon. A mark (representing a heavenly object) that crosses this line means that the object is rising or setting. The next circle represents 10°, the next 20° and so on until you come to 90° at the zenith (Z). The latitude of Edmonton is about 54° so the pole star would be located at an altitude of about 54° (point P).

To use an astrolabe all we need to do is mount a transparent circular plate on top of the lines shown in the diagram above. This plate rotates about P to represent the daily motion of the sky. On the plate we make marks to represent the stars and a circle to represent the path of the sun through the sky (the ecliptic). On the outside of the circles is a circular scale with markings from 0 - 23 h. This represents star time. As we rotate the plate we can observe when various stars rise and set. For each day of the year we can find the place the sun is on the ecliptic. When we know this we can tell when the sun will rise or set.

The rotating plate of an astrolabe is called the rete.

Underneath the rete is the climate.

The main body of the astrolabe is the mater.

Some typical latitudes:

Lethbridge	49.5°
Calgary	51°
Red Deer	52.25°
Lloydminster	53.5°
Edmonton	53.5°
Peace River	56°
Ft. McMurray	56.5°
Yellowknife	60°

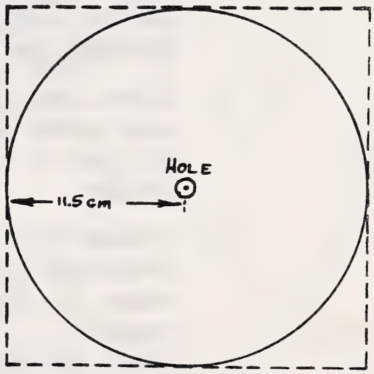
Activity

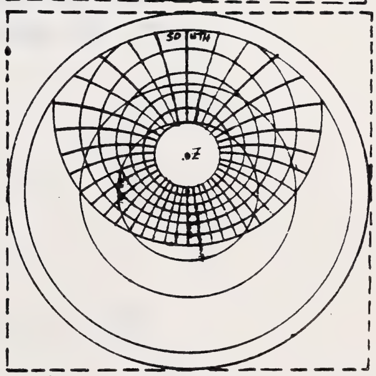
Pages 4a, 4b, 4c, 4d, 4e, 4f and the plastic plate after page 4h contain the main parts necessary for the construction of an astrolabe.

1. Examine pages 4a, 4b and 4c. Choose the diagram that most closely represents your latitude. You will not need the other two at your latitude. Carefully cut out the one you have chosen. You may wish to save the others for comparison purposes.

2. From a piece of cardboard or 0.50 cm plywood, cut out a 23 cm diameter circle or a square with a side of 23 cm. This will form the mater of the astrolabe. Find the centre of this circle or square and drill or punch out a hole large enough to contain the diameter of a small bolt. The bolt should have a diameter of from 2 mm to 5 mm.

3. Punch a hole (the same size as that in the cardboard or plywood) through the point marked P on the climate that you cut out in step 1.





Glue Climate to Mater

Using wood glue or rubber cement attach the climate to the piece of wood or cardboard. <u>Be sure that the hole in the climate lines up with the hole in the cardboard or plywood mater</u>.

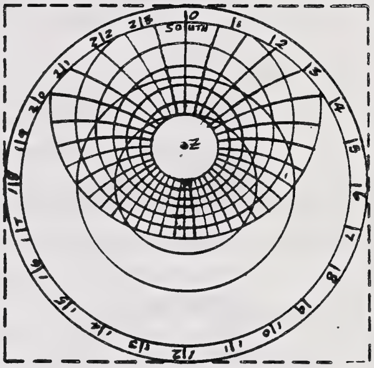
4. Cut out the hour markings from page 4d. Glue the hour markings on the cardboard (or plywood) mater. They should lie outside the circle of the climate. <u>Be sure the 0 h mark lines up with the 180° (south) azimuth line</u>.

5. From the plastic sheet (found following page 4h) cut out the large black circle. This will form the <u>rete</u>. <u>Be sure to retain the tab at the top of the circle</u>. Do not cut it off.

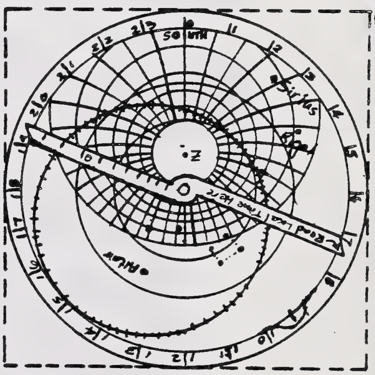
6. Carefully cut a hole (the same diameter as the bolt you will use) in the centre of the rete circle (at the point labelled Polaris). One way of doing this is to use a ballpoint pen and the appropriate size of hole in a geometry set or a drafting set hole template. Place the hole over the plastic rete with its centre at the Polaris dot. Run the pen around and around the hole until it cuts through the plastic.

7. From page 4e cut out the astrolabe rule and again cut a hole (the same diameter as that of the bolt) at the dot in its centre.

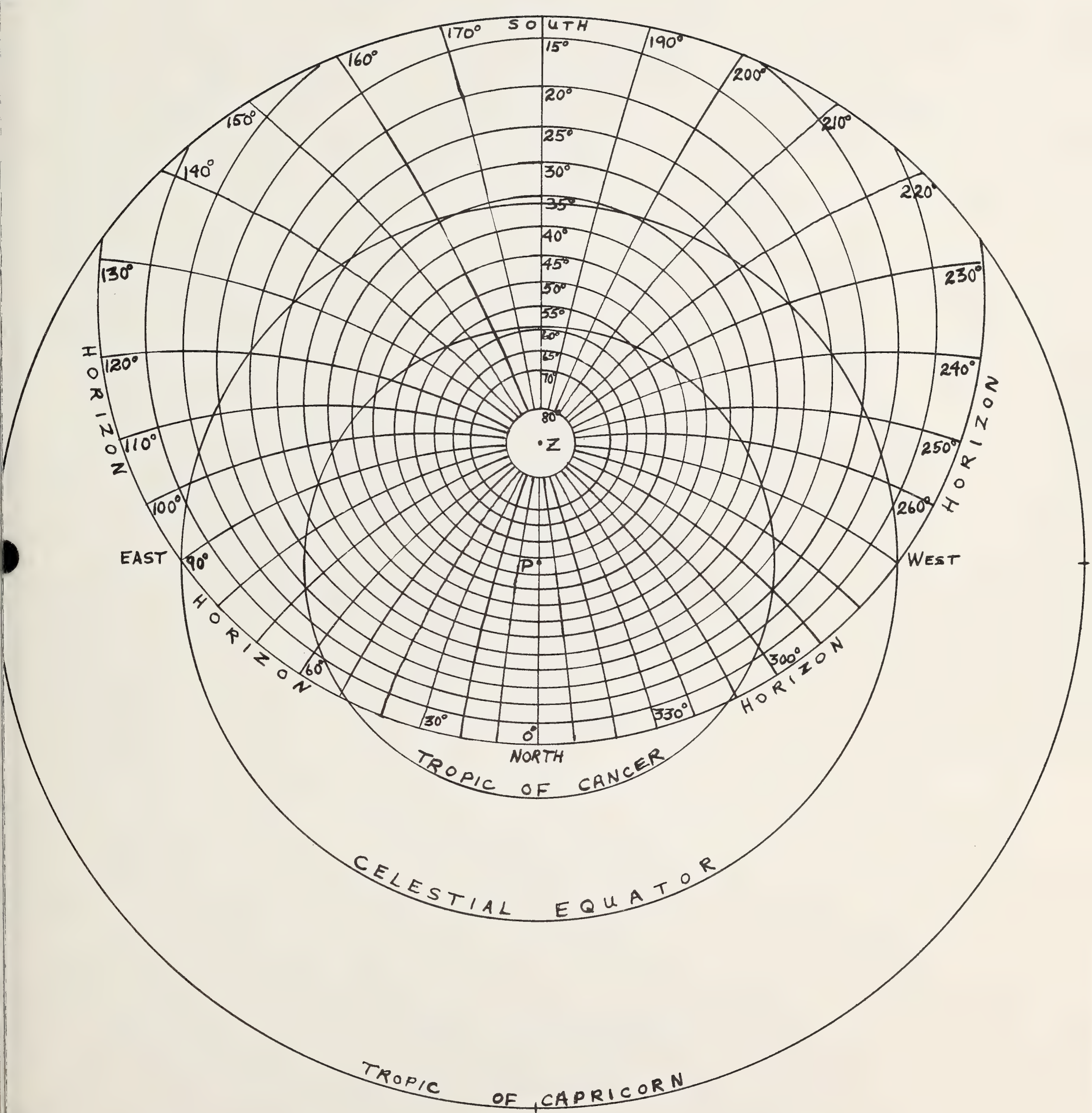
8. Fasten first the plastic rete and then the astrolabe rule to the mater and climate using the small bolt to hold them together. The rete should turn freely about the bolt. You are now ready to use the astrolabe.



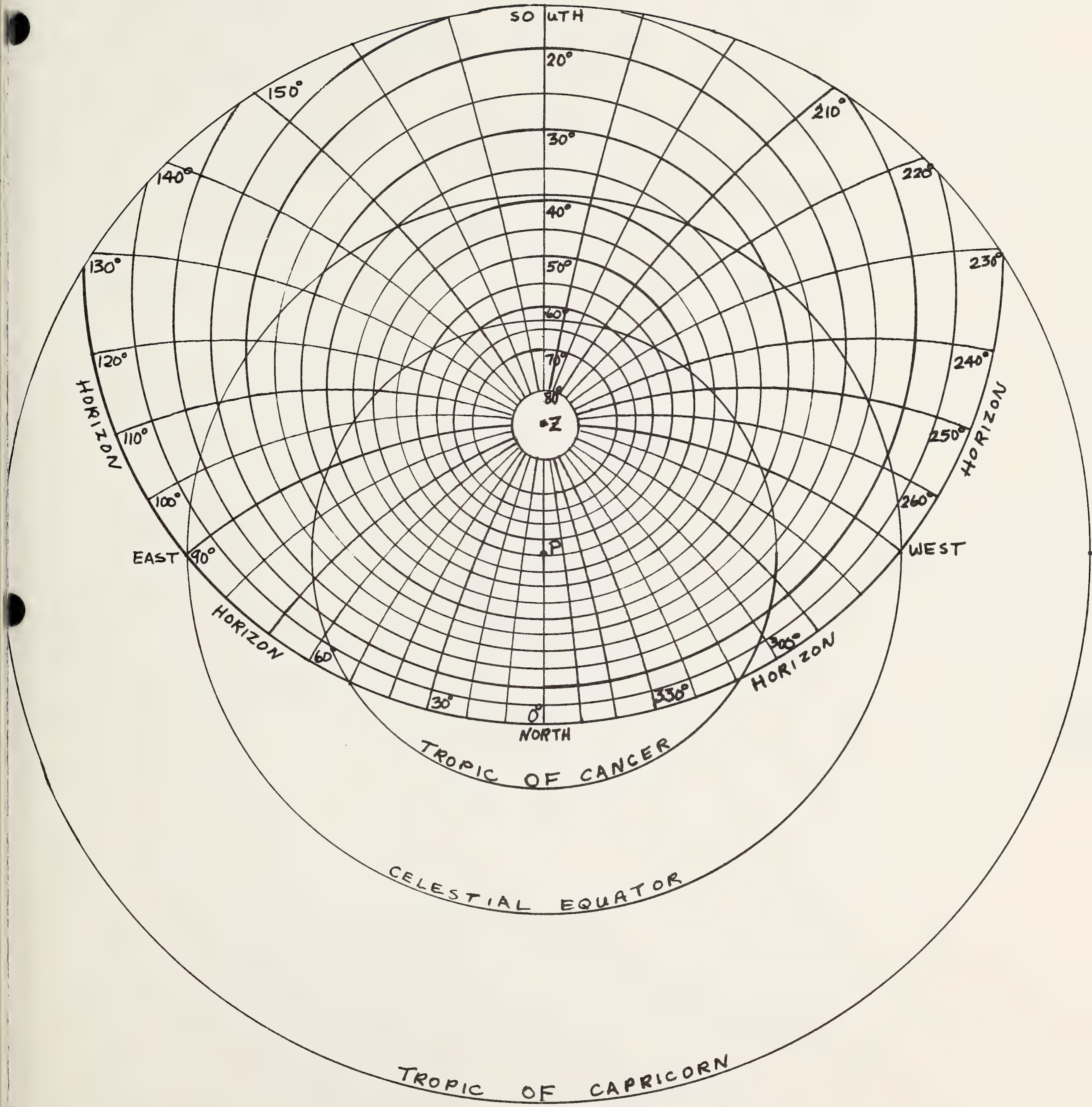
Glue Hour Markings to Mater



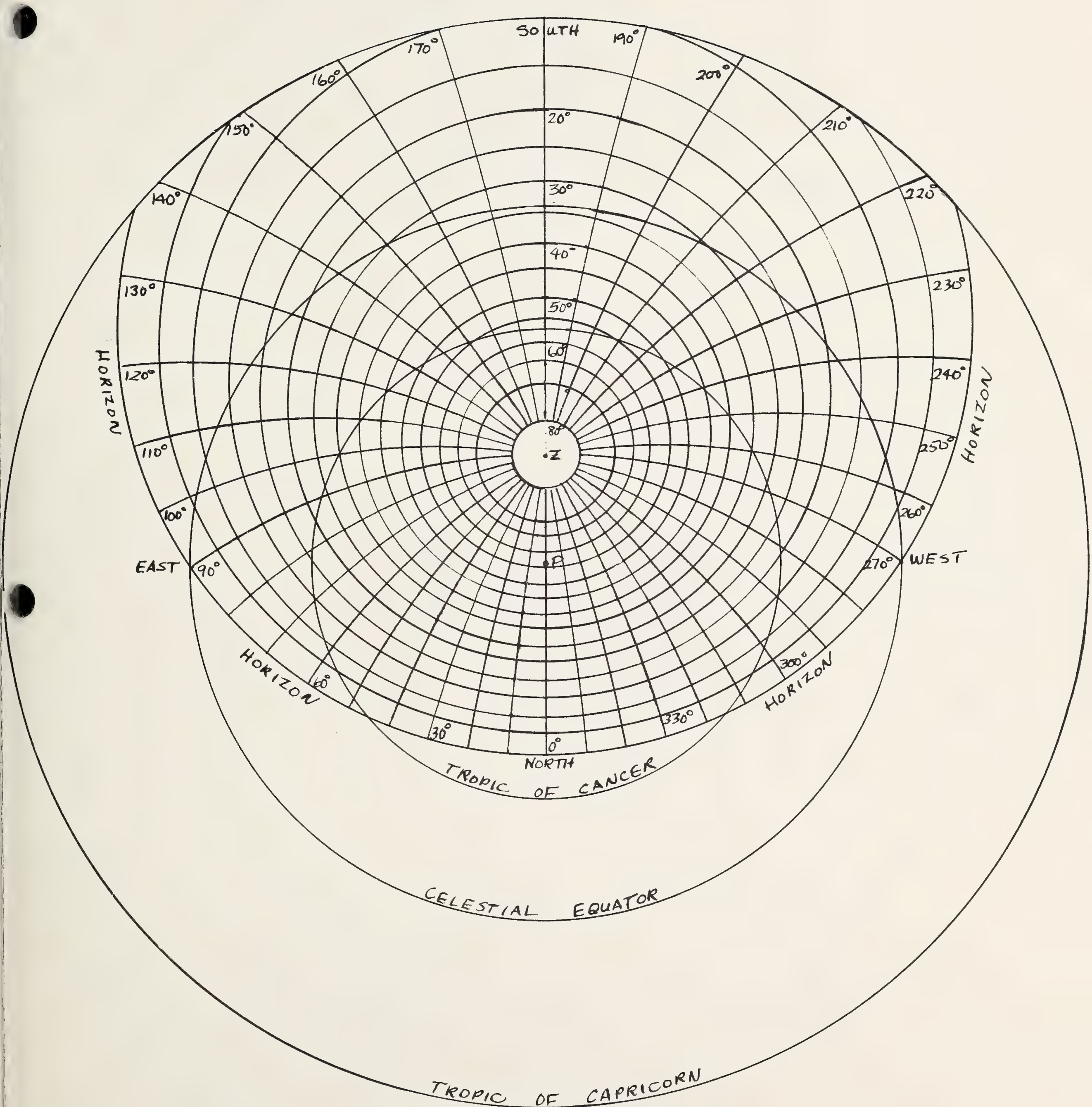
Completed Astrolabe



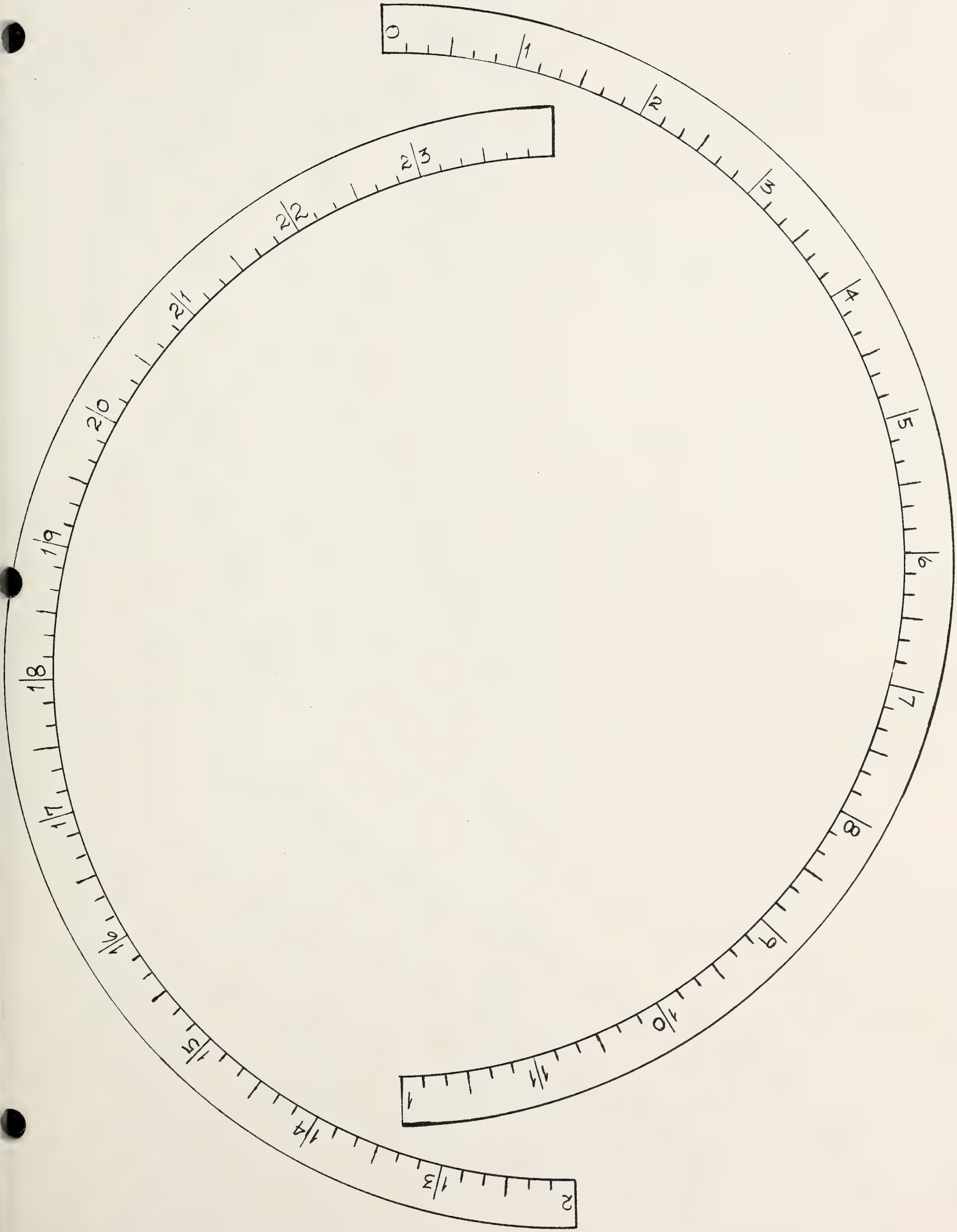
Climate for $52\frac{1}{2}° - 54\frac{1}{2}°$
(Edmonton - Lloydminster - Edson and Vicinities)



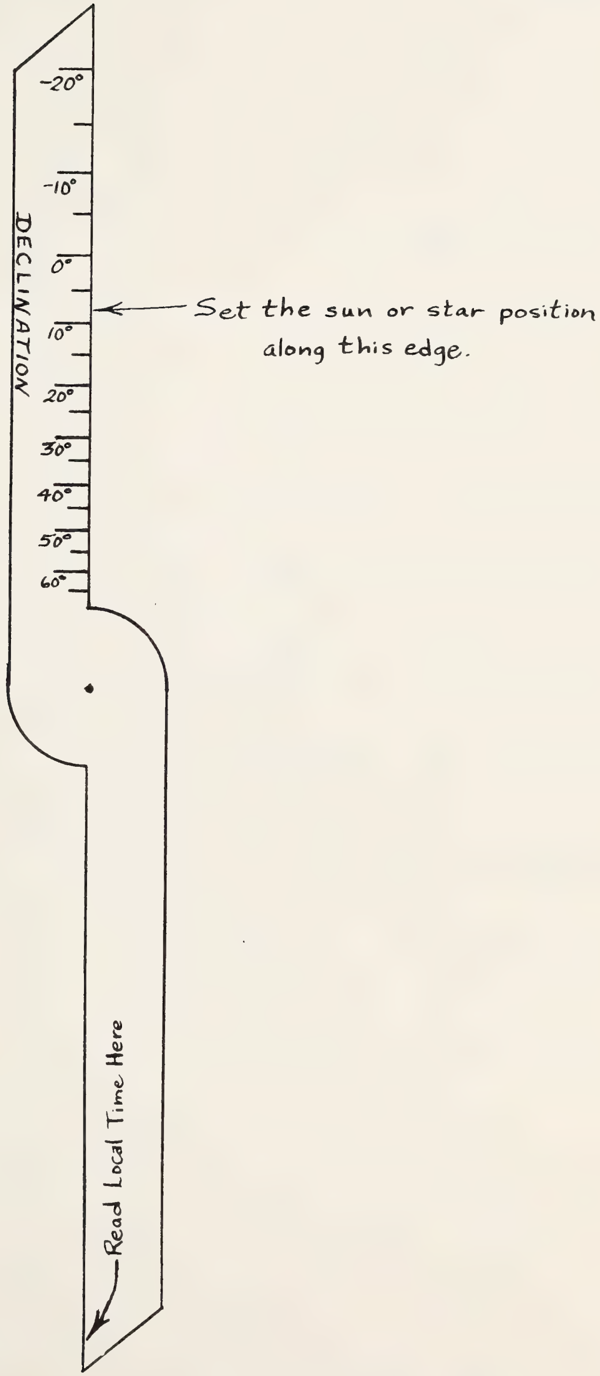
Climate for 49° – 52°
(Calgary and Southern Alberta)



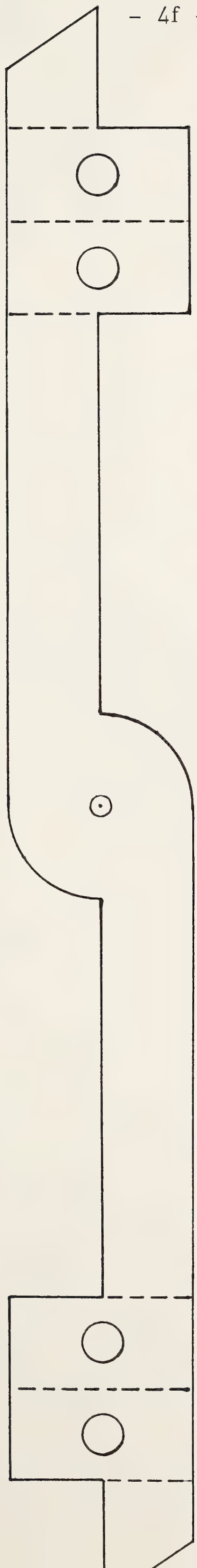
Climate for 55°-58°
(Peace River Country, Ft. McMurray)



TIME SCALE FOR ASTROLABE



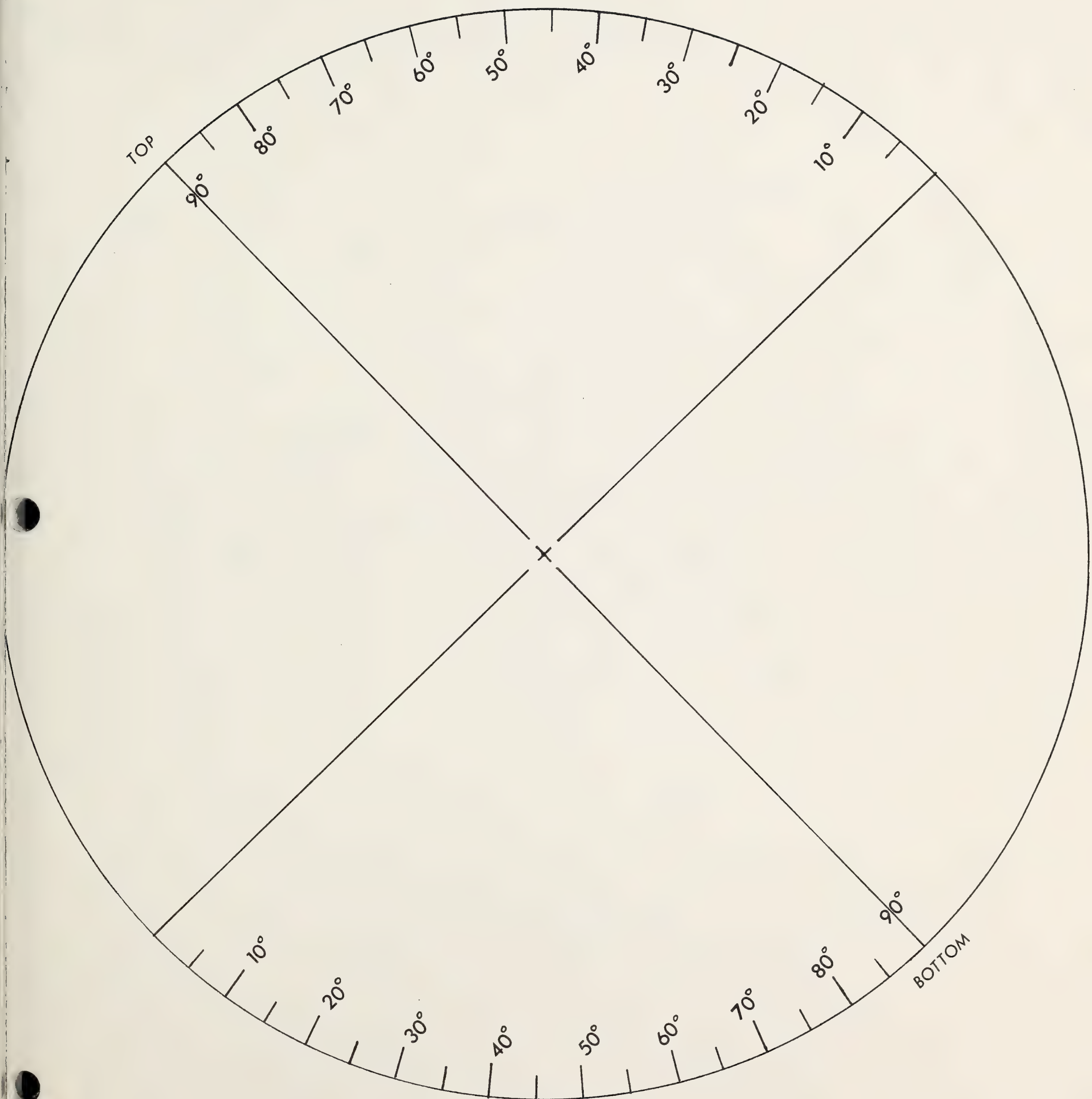
Astrolabe Rule



This is the alidade. It is to be cut out, folded on the on the dotted lines and glued so that rectangles with the holes are flat against each other and stand up at right angles to the rest of the alidade.

It is to be attached to the back of the astrolabe and used to determine star altitudes.

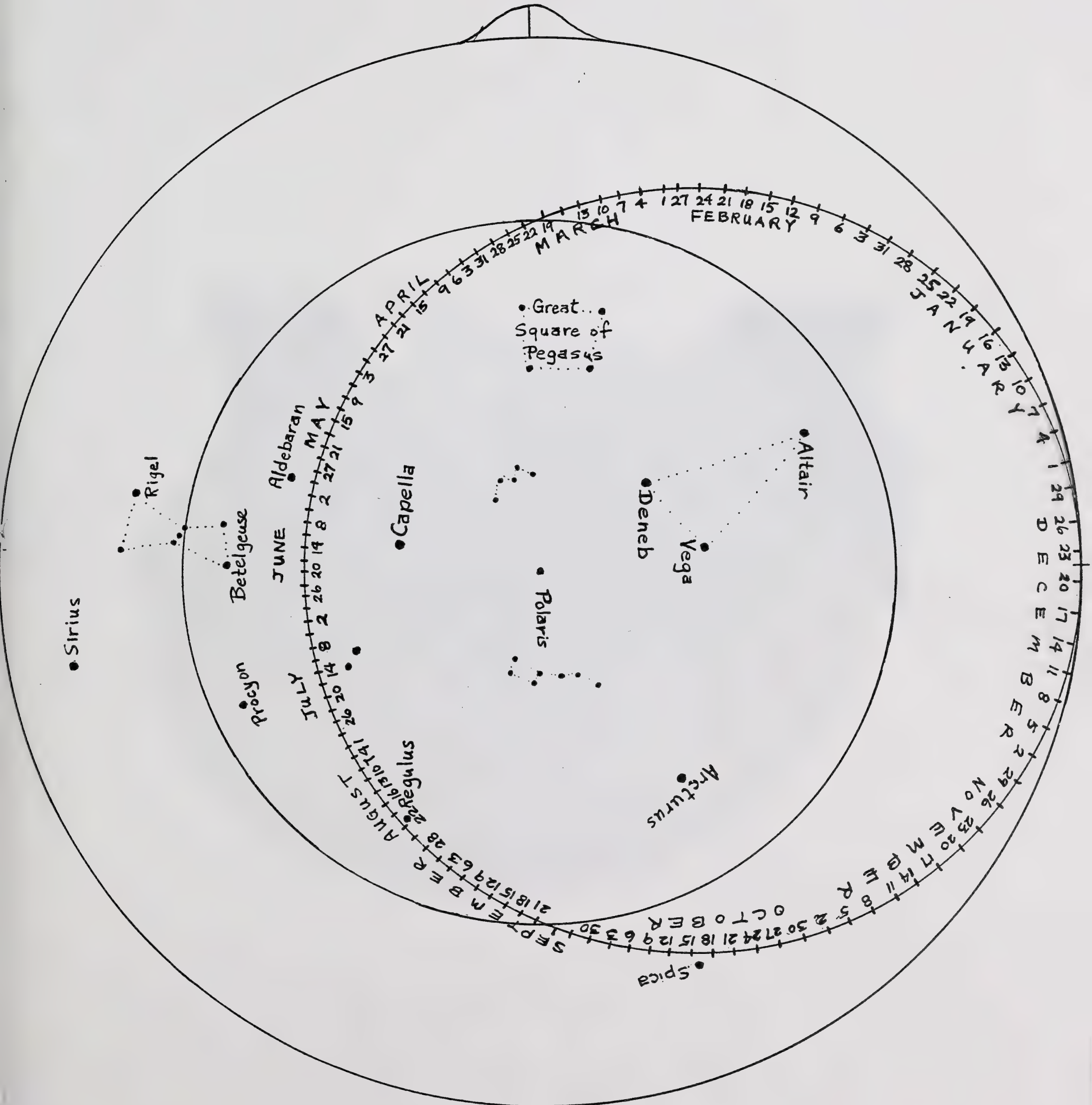
Never look at the sun directly through the holes of the alidade.



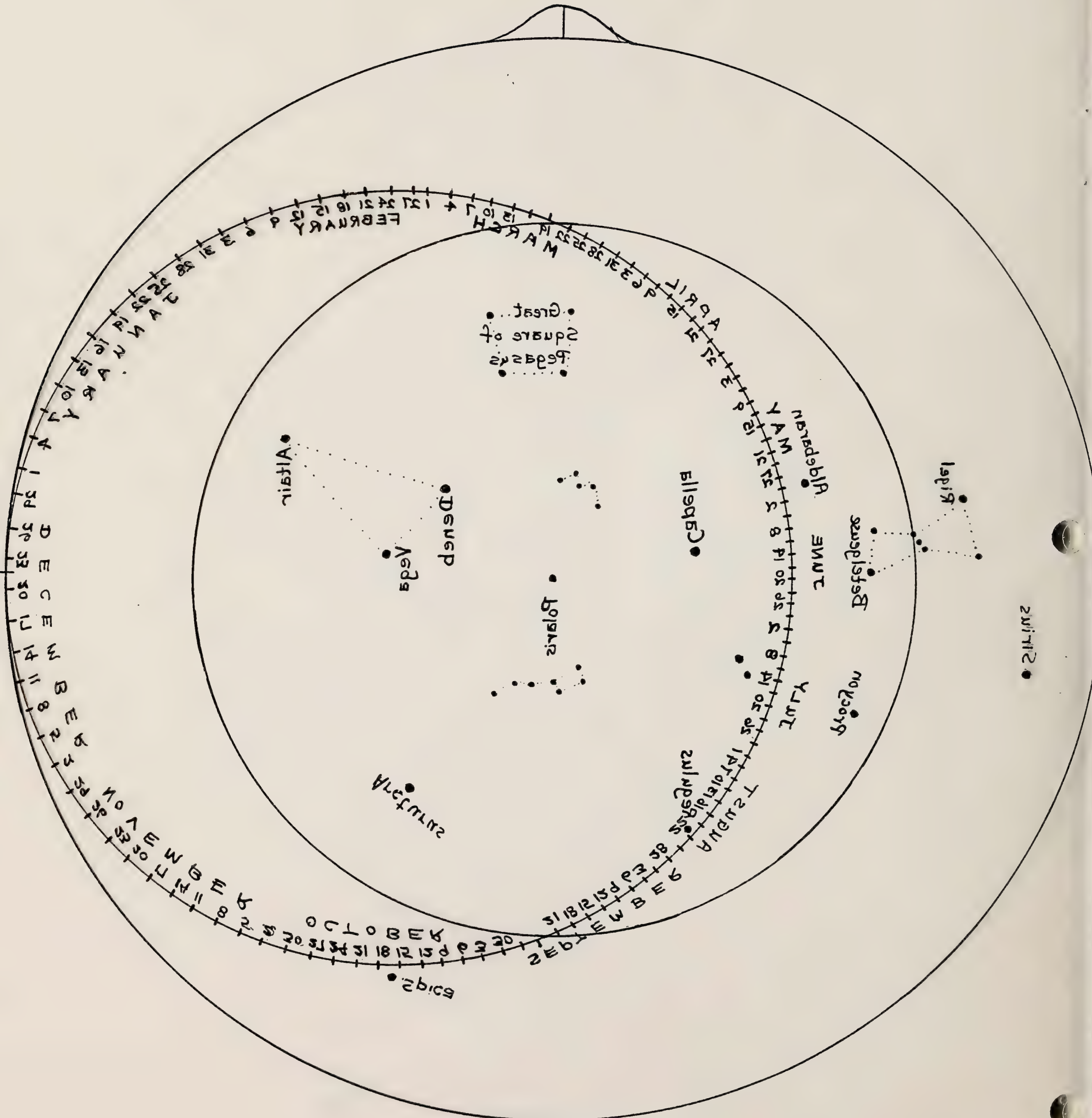
ANGLE SCALE FOR THE BACK OF THE ASTROLABE

(place it under the alidade)

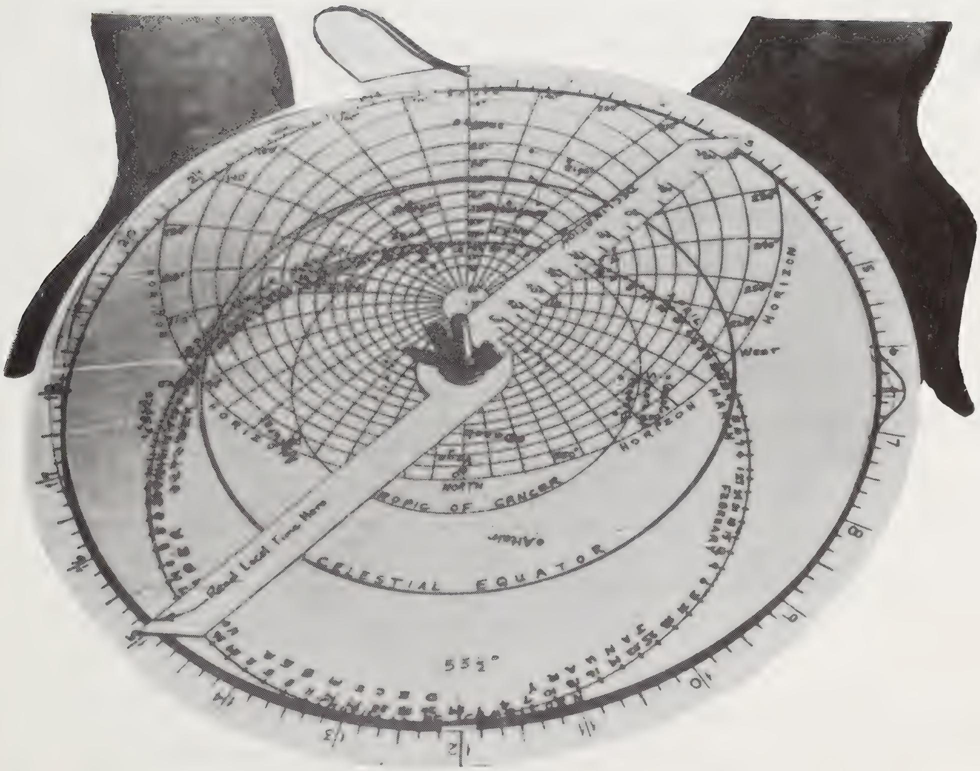
Rete Design for Astrolabe
(Stars Brighter Than Magnitude 3.5)



Rete Design for Astrolabe with Sun Positions for Days of the Year and Brightest Stars



Rete Design for Astrolabe with Sun Positions for Days of the Year and Brightest Stars



The Completed Astrolabe

Questions

1. Turn the plastic rete slowly around in a clockwise direction. Notice that some stars cross the horizon line and others do not.

   (a) Name one star that does not cross the horizon line.

   ____

   (b) Name one star that does cross the horizon line.

   ____

2. Find the star time at which the star Sirius rises. (Set the dot representing Sirius directly on the east horizon line. What hour and minute does the mark on the tab at the edge of the circle point to?)

   ____

   ____

3. At what star time does the star Regulus rise? (Regulus is near the August 22 position of the sun).

   ____

4. At what star time does the star Sirius set? (Place the dot representing Sirius on the west horizon line to represent its setting).

   ____

   ____

5. At what star time does the star Procyon set?

   ____

6. At what star time does the star Altair rise?

   ____

7. At what star time does the star Capella set?

   ____

8. Today's date: ______________
Find the position of the sun for today. (Find today's date on the date circle - (ecliptic circle) - on the plastic rete.) At what time does the sun rise today? (Set the mark for today's date on the eastern horizon line. Read the time from the marked tab.)

____

At what star time does the sun set today?

____

How many hours of daylight will there be today?

Note: to subtract a large time reading from a smaller one add 24h to the smaller reading. For example, subtract 11:34h from 3:23h:

= 3:23h - 11:34h
= (3:23 + 24:00) - 11:34
= 27:23 - 11:34
= 26:83 - 11:34
= 15:49h

9. At what star time does the sun rise on March 22?

____

On September 23?

____

10. At what star time does the sun rise on May 30?

____

At what star time does the sun set on October 15?

____

11. So far we have been talking only about star time (also called sidereal (sĭ dēar´ ē al time). How is this related to clock time? The difference lies in the fact that sidereal time is measured according to the stars and clock time is measured from the sun. The sun appears to move eastward among the stars day by day and so the two times are different except at only one time of the year.

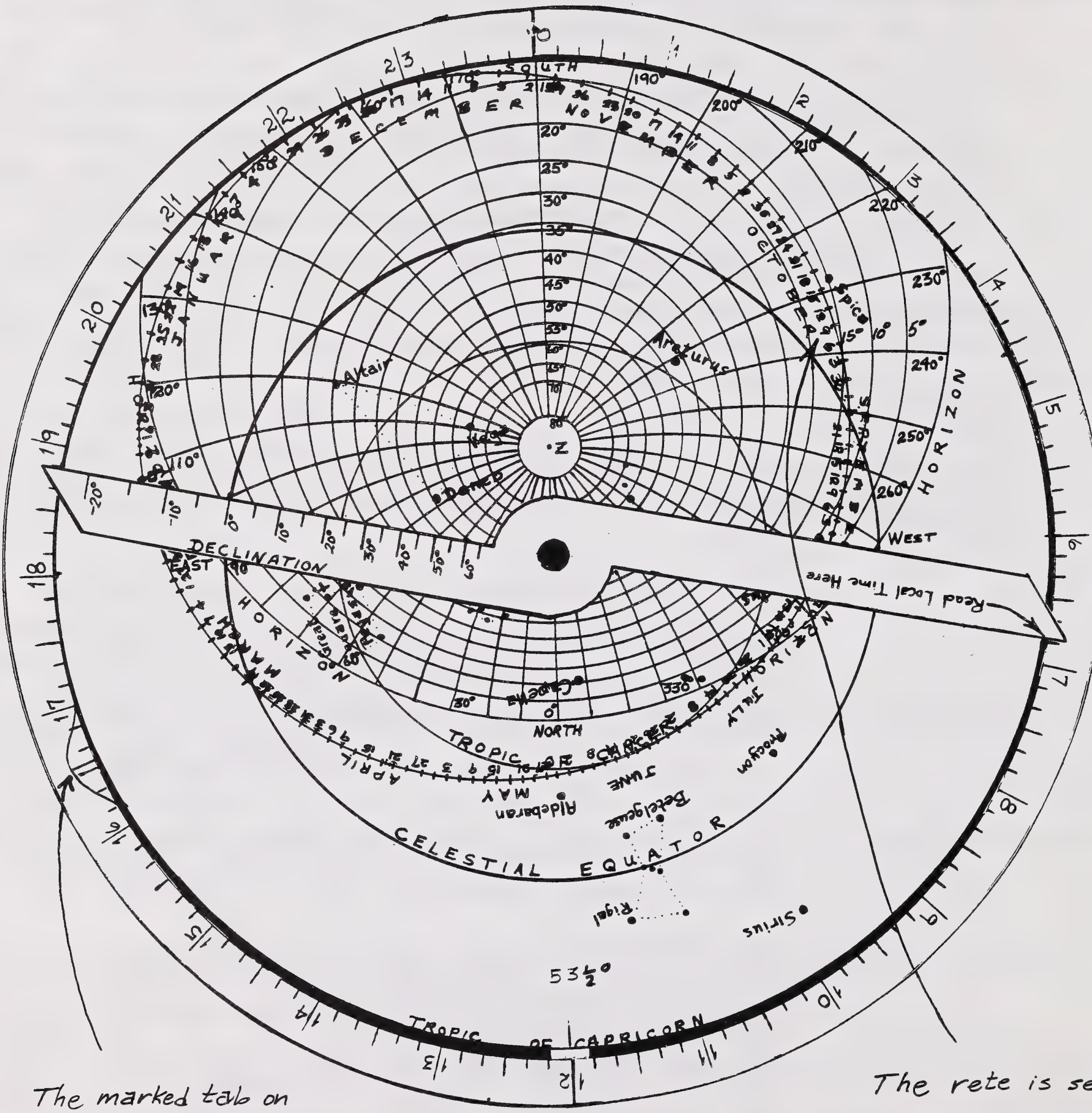
As you read the next paragraph refer to the illustrations on pages 7a and 7b.

Near autumnal equinox, September 20 or 21, star time and clock time are the same. At all other times they are different. But with the astrolabe it is a fairly easy matter to read both the star time and the clock time. Let's take an example. Supppose the date is October 9 and in the afternoon we take a reading on the sun's shadow and find that the sun is at an altitude of 16°. Set the rete so that the point labelled October 9 is at the 16° line in the western part of the sky (right side of the astrolabe). From the marked tab you can read star time. It should be somewhere between 16 00 and 17 00 in Alberta. To read clock time set the rule (the device that turns above the rete) so that the edge with the degree markings is directly over October 9. (Make sure that the October 9 mark stays on the 16° altitude line while you are doing this.) Now read the time on the other edge of the rule according to the instruction written there. Your reading should be somewhere between 15 00 and 16 00 in Alberta. Try it with your astrolabe. Note that star time is ahead of clock time.

The time that you read is not yet true clock time. There are two corrections to be made (three during periods of daylight saving time). The time you read from the rule is actually the time that a sundial would show—it is called <u>local solar</u> time. To obtain clock time we must make the following corrections:

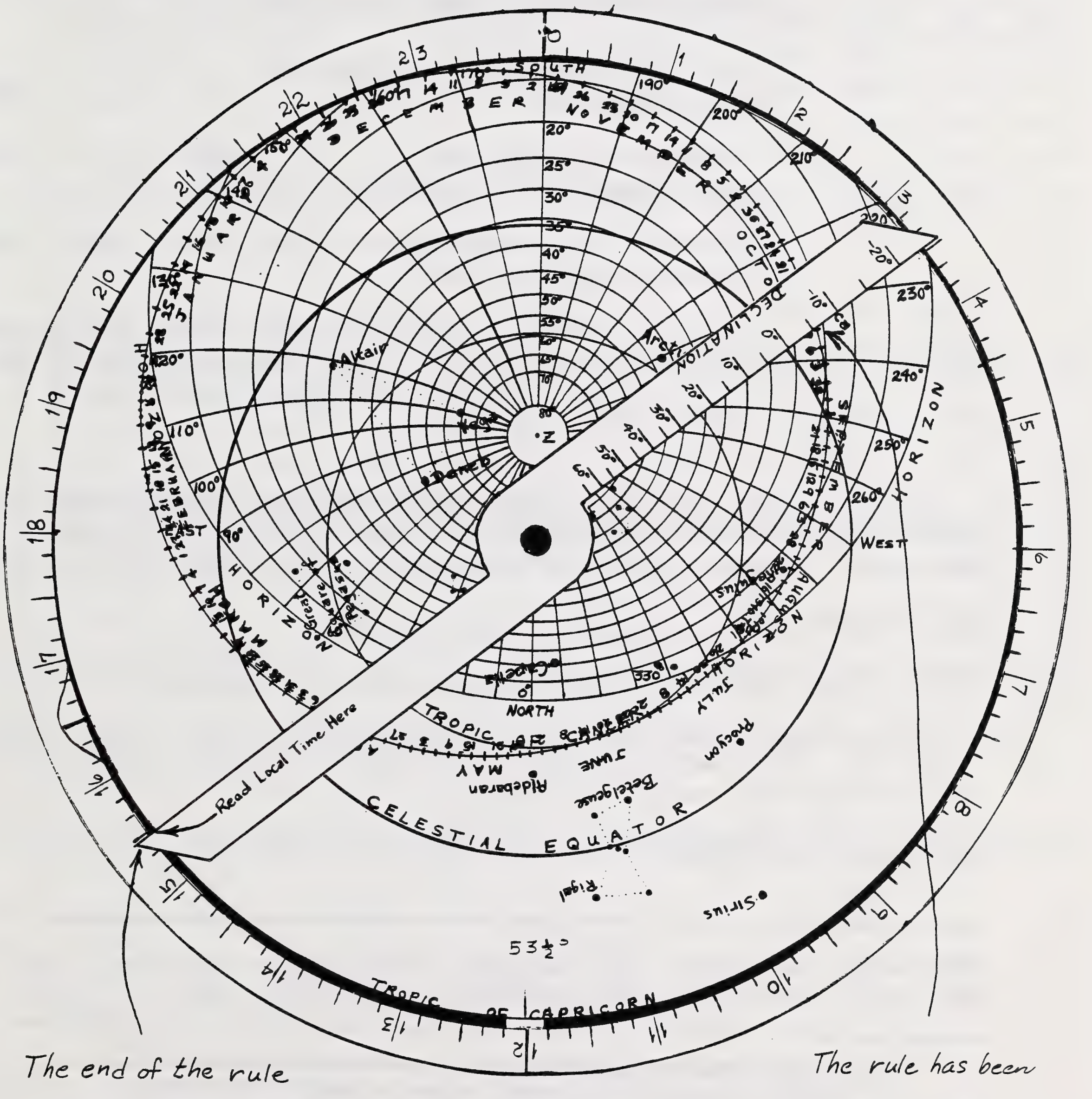
(1) For varied reasons the sun does not move evenly at a constant speed across the sky. To solve the problem geographers have invented the <u>mean</u> sun. Imagine a sun that travels eastward among the stars at a constant, unchanging rate throughout the year. This is the <u>mean</u> (average) sun and from it we obtain <u>mean</u> time. Sometimes the mean sun is ahead of the actual sun and sometimes it is behind. The difference can be as much as 16 minutes. The table on page 9 gives the number of minutes that must be added or subtracted from the astrolabe time reading for each day of the year.

(2) For convenience in doing business and in conducting daily affairs we live in time <u>zones</u>, regions in which everyone keeps the same time. Every place has a different <u>local</u> time - time according to the mean sun - but all areas in the same time zone have the same <u>standard</u> time. Most places in Alberta are <u>west</u> of the centre of our time zone and so we must add a correction for that fact. For Lloydminster and any points directly north or south of it add 20 minutes. For Edmonton and Calgary and Red Deer and any points directly north and south of them add 34 minutes. For points east or west of these three areas you will need to estimate a figure between 20 minutes and 60 minutes depending on the distance involved.



The marked tab on the rete shows the sidereal time of 16:33 h.

The rete is set so that October 9 is at 16° altitude.



The end of the rule shows the local solar time of 15:28h.

The rule has been rotated so that its edge lies on October 9.

(3) During periods of daylight saving time add 1h to the reading from the astrolabe rule. Now let's apply these corrections to our October 9 reading. Assume that we are in Edmonton, Calgary or Red Deer.

Time reading from the astrolabe rule (local solar time)	15:28
Correction for mean sun (local mean time) for October 9.	15:28 - 0:13 = 15:15
Correction for position in time zone (Mountain Standard Time)	15:15 + 0:34 = 15:49

Since, on October 9, we are usually still on daylight saving time we must add 1:00h. Thus clock time when the sun is at 16° in the western sky at Edmonton on October 9 is 16 49 or 4:49 P.M.

Now let's do an exercise in finding clock time using the astrolabe. The easiest time to observe the altitude of the sun is at sunrise or sunset - altitude 0°. Choose a clear day when you can observe sunrise or sunset.

Date of observation: ____________________

Clock time of sunset or sunrise: ____________________

Find the date market for this date of observation on the ecliptic circle of the rete. Set it at the eastern horizon line (0° altitude) for sunrise and at the western horizon line for sunset.

What is the sidereal time? (tab marker on the edge of the rete)

____

What is the local time? (set the edge with the degree markings at the date mark - read time from the opposite edge of the rule)

____

What is the correction for difference between mean and solar time?

(See table, page 9.) ____________________
Make this correction to your reading.

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
	min.	min.	min.	min.	min.	min.	min.	min.	min.	min.	min.	min.
1	+ 3.6	+13.7	+12.5	+4.0	-2.9	-2.4	+3.6	+6.2	+0.0	-10.2	-16.3	-11.0
2	4.0	13.8	12.3	3.7	-3.1	-2.3	3.8	6.1	-0.3	-10.5	-16.4	-10.6
3	4.5	13.9	12.1	3.4	-3.2	-2.1	4.0	6.1	0.6	-10.9	-16.4	-10.2
4	5.0	14.0	11.9	3.1	-3.3	-1.9	4.1	6.0	0.9	-11.2	-16.4	- 9.8
5	5.4	14.1	11.7	2.8	-3.4	-1.8	4.3	5.9	1.2	-11.5	-16.3	- 9.4
6	+ 5.9	+14.2	+11.4	+2.5	-3.5	-1.6	+4.5	+5.8	-1.6	-11.8	-16.3	- 9.0
7	6.3	14.3	11.2	2.2	-3.5	-1.4	4.7	5.7	-1.9	-12.0	-16.3	- 8.6
8	6.7	14.3	11.0	2.0	-3.6	-1.2	4.8	5.6	-2.2	-12.3	-16.2	- 8.1
9	7.1	14.3	10.7	1.7	-3.7	-1.0	5.0	5.4	-2.6	-12.6	-16.1	- 7.7
10	7.6	14.4	10.5	1.4	-3.7	-0.8	5.1	5.3	-2.9	-12.9	-16.0	- 7.2
11	+ 8.0	+14.4	+10.2	+1.1	-3.7	-0.6	+5.3	+5.1	-3.3	-13.1	-15.9	- 6.8
12	8.4	14.4	9.9	0.9	-3.8	-0.4	5.4	5.0	-3.6	-13.4	-15.8	- 6.3
13	8.7	14.4	9.7	0.6	-3.8	-0.2	5.5	4.8	-4.0	-13.6	-15.7	- 5.9
14	9.1	14.3	9.4	0.4	-3.8	-0.0	5.6	4.6	-4.3	-13.9	-15.5	-5.4
15	9.5	14.3	9.1	+0.1	-3.8	+0.2	5.8	4.4	-4.7	-14.1	-15.4	-4.9
16	+ 9.8	+14.2	+8.8	-0.1	-3.8	+0.4	+5.9	+4.3	-5.0	-14.3	-15.2	- 4.4
17	10.2	14.2	8.5	- 0.4	-3.7	0.6	6.0	4.0	-5.4	-14.5	-15.0	- 3.9
18	10.5	14.1	8.3	- 0.6	-3.7	0.9	6.0	3.8	-5.7	-14.7	-14.8	- 3.4
19	10.8	14.0	8.0	- 0.8	-3.7	1.1	6.1	3.6	-6.1	-14.9	-14.6	- 3.0
20	11.1	13.9	7.7	- 1.0	-3.6	1.3	6.2	3.4	-6.5	-15.1	-14.4	- 2.5
21	+11.4	+13.8	+ 7.4	-1.2	-3.6	+1.5	+6.2	+3.1	-6.8	-15.3	-14.1	- 2.0
22	11.7	13.7	7.1	-1.4	-3.5	1.7	6.3	2.9	-7.2	-15.4	-13.9	- 1.5
23	11.9	13.5	6.8	-1.6	-3.4	1.9	6.3	2.6	-7.5	-15.6	-13.6	- 1.0
24	12.2	13.4	6.5	-1.8	-3.4	2.2	6.3	2.4	-7.9	-15.7	-13.3	- 0.5
25	12.4	13.2	6.2	-2.0	-3.3	2.4	6.4	2.1	-8.2	-15.8	-13.0	+ 0.0
26	+12.6	+13.1	+5.8	-2.2	-3.2	+2.6	+6.4	+1.8	-8.6	-15.9	-12.7	+ 0.5
27	12.9	12.9	5.5	-2.4	-3.1	2.8	6.4	1.5	-8.9	-16.0	-12.4	1.0
28	13.0	12.7	5.2	-2.5	-2.9	3.0	6.3	1.3	-9.2	- 16.1	-12.1	1.5
29	13.2	....	4.9	-2.7	-2.8	3.2	6.3	1.0	-9.6	-16.2	-11.7	2.0
30	13.4	....	4.6	-2.8	-2.7	3.4	6.3	0.7	-9.9	-16.3	-11.4	2.5
31	+13.6	....	+4.3	....	-2.6	....	+6.3	+0.4	....	-16.3	....	+ 3.0

Table Showing Corrections to Clock Reading of the Astrolabe Rule Due to Differences in Position Between the Actual Sun and the Mean Sun.

What is the correction for your position in the time zone?

(See page 7, item 2.) ______________________________
Make this further correction to your reading.

Finally add 1h if the date of observation is within the period of daylight saving time (between last weekend in April and last weekend in October).

Your final corrected reading. ______________________________

What is the error in your reading? Subtract the time you actually observed the sun rise or set from the reading you found here.

If you cannot find a clear day for observing sunrise or sunset you could use the figures reported in a daily newspaper in place of the observations.

Time can also be determined by observing the altitude of stars. Traditionally, the astrolabe included a device on the back, called an alidade, through which stars could be sighted and their altitudes measured. The alidade (page 4f) will be used in a later exercise.

12. If you wish to use the astrolabe as a guide to observing stars and constellations put the plastic sheet over the diagram on page 4h and trace the extra dots shown as well as the months along the edges. To use the astrolabe this way set the month against the time you are observing the sky. If you want to observe at 8:00 P.M. in November, set November at 20 00h. The constellations that are enclosed by the horizon line are the ones that you will see in the sky at this time.

Ancient Observers of the Sky and Its Motions

We have now become acquainted with some of the stars and constellations that have been visible for thousands of years. For many of us this was a new experience. We are not exposed as much to the night sky as ancient peoples were. Nor do we need the sky to tell time or direction in the same direct way that they did. We have our timepieces and our streets and roads to help us out.

The fact is that we have been removed from direct contact with nature by the high technology of our age. In the city, street lights and smog and buildings obscure the sky. In the country, automobiles, enclosed spaces on machinery and mechanized activity of all kinds limit our exposure. Even when we are exposed to astronomy we may be tempted to think of it as a very special activity, hard to understand and very objective and mechanical. Indeed it has many of these characteristics, yet first and foremost astronomy is a human activity. Astronomers are people with their own unique personalities, feelings, interests, and understandings. The astronomers who operate the giant 500 cm telescope on Mt. Palomar are quite as human as were the ancient observers who stood on huge mounds to observe the stars. As we study the science of the stars we shall try to keep this important aspect of the science well in focus.

Technology removes us from contact with nature

Astronomy is a human activity

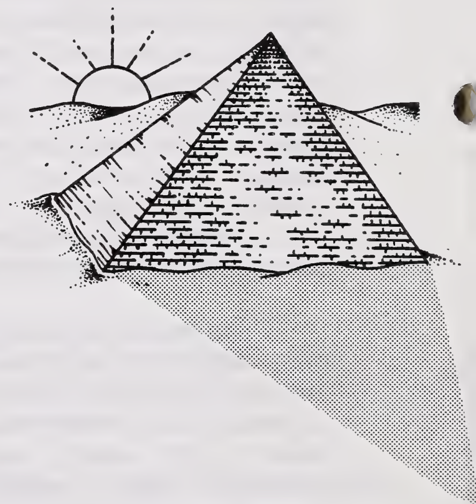
From the beginning of history there have been observers of celestial motions in all parts of the world. Each civilization and group of people had contributions of their own to make to our modern understandings of the heavens. Their knowledge and understandings may have been meagre but that knowledge has served as a base upon which more recent progress has been made possible. As we shall see, there were many situations in which astronomical knowledge among ancient peoples was quite remarkable, especially in view of the simple tools they had to use.

Ancient astronomers were found worldwide

The Egyptians

"Thou risest beautifully in the horizon of heaven
Oh living Aten who creates Life!
When thou risest in the eastern horizon
Thou fillest every land with thy beauty.
Thou art beautiful, great, gleaming and high over every land.
Thy rays, they embrace the lands to the limits of all thou hast made.
Thou art Re and bringest them all,
Thou bindest them (for) thy beloved son,
Thou art afar off, yet thy rays are on the earth;
Thou art in the faces (of men) yet thy ways are not known."

This poem, written about 4000 years ago reveals a central fact about Egypt. It is a country dominated by brilliant sunshine almost year round. Thus the movements of the sun and its effects dominated Egyptian astronomy. One of the needs that men have in daily activity is telling time. The Egyptians observed early in their history that one way of doing this was to observe the length of the sun's shadow. This led eventually to the invention of the sundial, one of the earliest ways of telling time.



Egypt is dominated by one other fact of life. For the most part the land is barren desert, baked day after day by the blazing sun. However, right through its centre, from south to north runs the Nile River. The seemingly magic life-giving powers of water produce luxurious vegetation along the banks of the river. This contrasts sharply with the hot, brown desert sand next to it. Today as in ancient times, Egypt's population is concentrated near the narrow strip of land along the Nile River.

Flooding of the Nile

The most important event of the whole year for the Egyptian people was the flooding of the Nile. This not only thoroughly soaked the ground along the banks of the river — it also laid down a rich new layer of silt. It was this event that led the Egyptians to a discovery of the 365 day year. In the middle of July the bright star Sirius began to rise just ahead of the sun in the early morning in

Sirius rose just before the sun in mid-July

ancient Egypt. This was a signal to the Egyptians that the Nile flooding was due soon. By counting the days between two successive appearances of Sirius the Egyptians discovered that the year contained very close to 365 days.

One year - the time between successive appearances of Sirius before the rising sun

Activity

We live at a different latitude than the Egyptians did and the coordinates of the sky have changed since the time of the ancient Egyptians. Nevertheless you can use your astrolabe to determine when Sirius is visible just before sunrise.

Use your astrolabe to determine the date when Sirius rises just before the sun

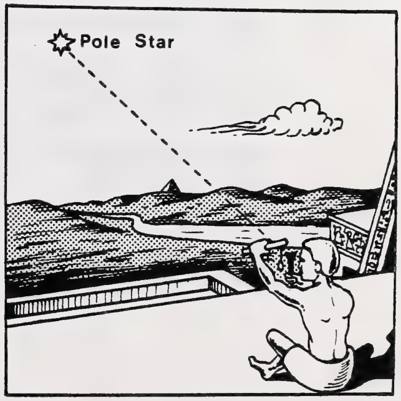
Assume that Sirius is at an altitude of 5° when the sun rises. On what day of the year does this take place? Turn the rete of the astrolabe until Sirius is on the 5° line in the east part of the sky. Then note which day of the year is on the eastern horizon.

____.

Send this in for correction

The Egyptians were also skilled mathematicians. By using simple instruments they were able to lay the base of the Great Pyramid extremely close to a straight north-south orientation within 5″ of an arc or $\frac{1}{250\ 000}$ of a complete circle. It is thought that at one time one of the shafts in the pyramid pointed to the pole star. Some have suggested that some pyramids and temples of Egypt were used as astronomical observatories in which priests made careful observations of the stars and sun. One of the simple instruments used for astronomical observations was the merkhet. It was used along with a plumb bob to make star sightings.

The Great Pyramid is accurately aligned in a north-south direction



In Egypt the sun rises and sets with great regularity. There is little change in the weather from season to season and the Nile floods regularly every year with a high degree of certainty. This produced a sense of security and well-being for the Egyptian people. The same was not true, however, for the people of Mesopotamia, the Land Between the Rivers.

Egypt is a land of uniformity and regularity

The Mesopotamians

This land is located for the most part near the two great rivers, the Tigris and the Euphrates. It is a fertile land but unlike Egypt, storms often sweep across the land sometimes causing much destruction. In addition, the two rivers flood frequently, sometimes destroying crops and damaging buildings and even taking human lives. Life was much less certain and secure for the people who lived here than it was for the Egyptians. The people of this area therefore saw the universe as a battle ground for opposing forces - sometimes the forces of order won out and sometimes the forces of chaos. It was no doubt here that astrology (the association of events in the heavens with those on earth) began. It became very important to observe the events of the heavens. Out of this concern came a number of important contributions to astronomy.

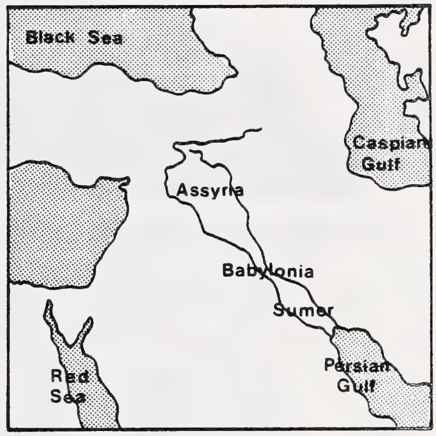
Mesopotamia is a land of some uncertainty and insecurity

The universe - a battle-ground for the forces of order and chaos

Beginnings of astrology

The oldest civilization in this area was that of the Sumerians (before 1500 B.C.). They listed 25 stars and divided the year into two seasons (summer and winter). They used an intercalary month (a 13th month added every so many years) to correct the 360 day calendar. For them the day began at sunset and time during the night (as with the Egyptians) was kept with a water clock.

The Sumerians



The first real advances in astronomy began with the Babylonians (Old Babylon about 2000 B.C., and the new empire, 612 B.C. - 539 B.C.) and the Assyrians (2000 B.C. - 612 B.C.).

The main timepiece for these peoples was the moon (instead of the sun as for the Egyptians). The month began when the first sliver of the new moon appeared in the west after sunset. The day began at sunset. The moon was associated with moisture and fertility and became an important deity.

Beginning of month - evening

The five planets, and especially Venus (by the Assyrians) were observed carefully. The planets seemed to wander at will through the heavens, something which they believed only gods could do, and so they were closely associated with gods. Conjunctions of the planets became very important events. Some have suggested that the names of the days of the week came from the Mesopotamians. Each of the deities was honored on a certain day of the week. Sun-day, Mon (moon)-day, Tues (Mars)-day, Woden (Mercury)-day, Thor (Jupiter)-day, Freya (Venus)-day and Satur (Saturn)-day. The present form of the names is Norse but they came originally from the Babylonians.

Sun - day
Moon - day
Mars - day
Mercury - day
Jupiter - day
Venus - day
Saturn - day

One of the problems that the Babylonians worked hard to solve was how to fit the month into the year. The month on the average has $29\frac{1}{2}$ days - an awkward figure. But the sun and the moon move at different apparent speeds at different times of the month and year. By years of patient observation and calculation the Babylonians drew up complicated tables to predict when and where the moon would appear. In fact the Babylonians were best at observation and calculation. They had a good knowledge of mathematics to back this up.

Problem - How does the month fit into the year?

As a result of the patient observations that went into these tables, the Babylonians were able to predict eclipses, especially eclipses of the moon. It is very interesting that they did not have any theories to go by - only long observations made over hundreds of years.

Tables of observation were called epherimedes (e-fi-mare-i-deez)

In addition they made some interesting observations of planetary motions. The motions of the planets are even more complicated than those of the sun and the moon. Their main concern was to be able to predict the "station" or position of a planet for a certain time. This was important to them because they believed that there was a powerful connection between the positions of planets and events in the lives of people.

Finding planet stations

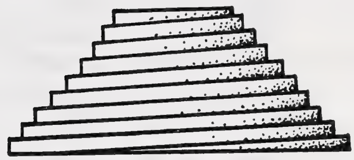
Finally, the Mesopotamians gave us the concept of the zodiac. The movements of the sun and moon can best be observed against the background of the stars. Because of their interest in the motions of the sun and the moon they came to know this part of the sky (covering 10° on either side of the ecliptic) very well. The constellations Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces and Aries, all on the ecliptic, were named as far back as 650 B.C.

The zodiac and its constellations

The earliest record of an eclipse was made by a Babylonian in 2283 B.C. By 500 B.C. a Babylonian astronomer had discovered that the year is 365 days 6 h 15 min 41 s long which is very close to the correct value.

Earliest eclipse record
Present length of sidereal year is 365d 6h 9min 10s

What instruments were used by the Babylonians? The first and most important were the ziggurats (mounds of earth or pyramids). Mesopotamia is largely a flat country with few natural hills or high points. The Babylonians solved this problem by making their own. The ziggurats were combined temple-observatories from which accurate observations could be made. They were laid out by observing carefully the rising and setting of the equinoxes (the points in the sky where the sun is located March 20 and September 22).



The Shape of a Ziggurat

Another instrument used by the Mesopotamians was the gnomon. It was simply a stick placed vertically in the ground. The length of its shadow at noon could be used to determine the time of year. The direction of the shadow indicated the time of day.

The gnomon

Questions

1. At what time of the day is the sun the highest? Do not look directly at the sun.

____

2. You may have noticed that the sun is not straight south at 12:00 noon. Why do you think this is so?

____

____

3. At what time of the year would the sun be highest in the sky at noon? (Use your astrolabe to discover this. Turn the rete until the ecliptic circle is closest to Z (zenith) on the 0 (south line).

____

4. At what time of the year would the sun be lowest in the sky at noon? (Ecliptic circle farthest from zenith on the south line).

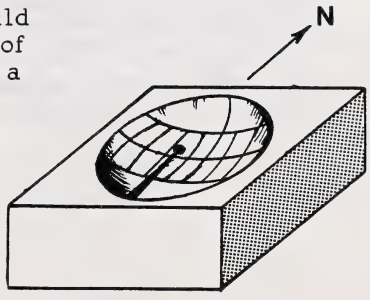
____

5. When the sun is at an equinox, how high in the sky is it at noon?

____

Another instrument used by the Mesopotamians was the polos. It was a hollow sphere that could catch the sun's rays on its surface. The path of the sun was traced by means of the shadow of a bead placed at the centre of the hemisphere.

A fourth instrument was the clepsydra or water clock. This could be used to tell time when the sun was not shining.



The number system of the Babylonians was very useful in their astronomical work. It was a sexigesimal number system (based on the number 60). This number works well because 60 is easily divisible by 2, 3, 4, 5, 6, 10, 12, 15, 20, and 30. The numbers 12 and 24 are closely associated with the sexigesimal system. This is no doubt the case because a circle can easily be divided into 12 or 24 parts simply by using a straight edge, compass and the radius of the circle.

Sexigesimal number system

Division of circle

The use of the sexigesimal system accounts for the fact that 1 h = 60 min and 1 min = 60 s. Note also that 60 × 6 = 360, the number of degrees in a circle.

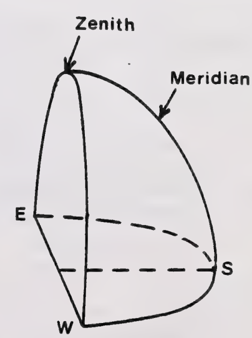
The Chinese

Astronomers were already active in China before the time of Christ. Eclipses of the moon were recorded as early as 1216 B.C. Astronomy was a very important activity of ancient China partly because the emperor himself was considered the "Son of Heaven" and partly because the fortunes of government were thought to rest on observations of the heavens. Astronomers enjoyed great prestige but also were given great responsibility.

The Chinese were especially impressed with the motion of the Big Dipper and the idea of north and south. They divided the sky into four quarters with China itself at the centre as "the Middle Kingdom."

North-south important to the Chinese

One quite original contribution to observational astronomy was made by the Chinese. They did not measure times of rising and setting of heavenly bodies as the Mesopotamians did. Instead they noted the time at which a star crossed the meridian - a line which runs from directly overhead (the zenith) to straight south. This may have come about partly because of their interest in focussing attention on the north-south direction.



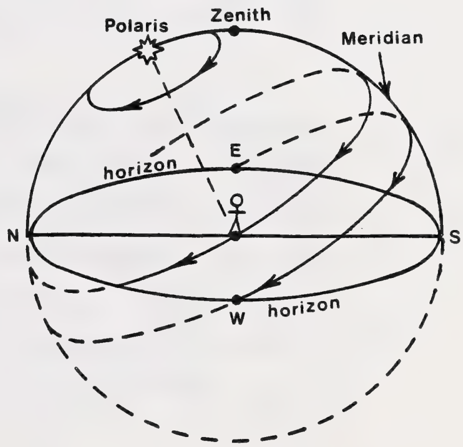
By using the meridian the Chinese made observation much easier because when a star is on the meridian it is as high in the sky as possible and much easier to see than when it is near the horizon. By using this system the Chinese were in effect using an equatorial coordinate system, the system which is used today in astronomy for locating celestial objects.

Meridian observation easier than horizon observation

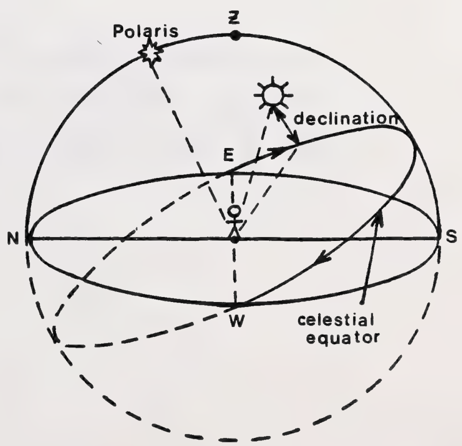
The Equatorial Coordinate System

When you go outside and stand on a flat level piece of ground, the sky appears as a huge inverted "bowl". If you extend this bowl to the other side of the earth it forms a complete sphere around the flat surface of the earth on which you are standing. Once a day this complete sphere seems to make one complete rotation about the place where you are standing, carrying the sun, moon and stars with it. It appears to rotate around the pole star, Polaris.

As you look outward you can see the horizon, the line along which the earth meets the sky. It seems to form a circle all the way around you. If you extend this line into the bowl of the sky it forms the celestial horizon. This is the line along which the sun, moon and stars rise and set. The point straight above you is called the zenith. It is, of course, 90° from all points on the horizon. The line which passes through the zenith to the south point on the horizon is the meridian.

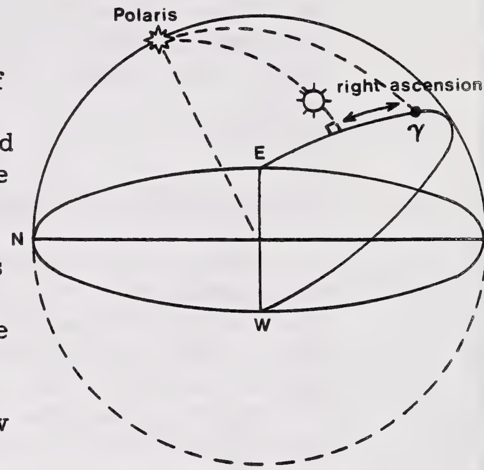


Suppose that there is a star that rises directly east. As the sky bowl turns, the star traces a circle through the sky until it sets directly west. The line or circle that this star traces is called the celestial equator. It continues on the far side of the earth below the horizon. Any object (like the sun on March 20 or September 22) that rises directly east or sets directly west lies on the celestial equator. This is the zero line from which we can measure distances up and down in the sky. Such measurements are called declination.

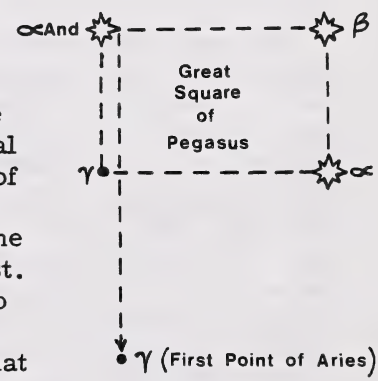


The belt of Orion has a declination of about 0° because it is on the celestial equator. Polaris has a declination of 90°. The zenith for Edmonton has a declination of about 54° (the same as the latitude of Edmonton).

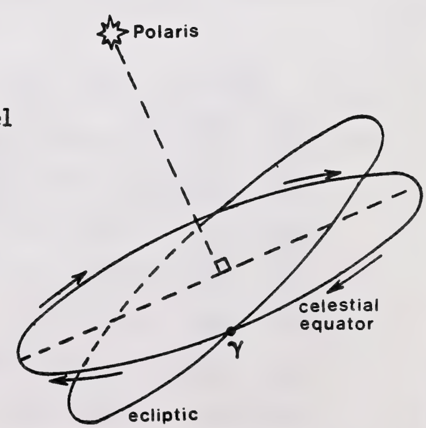
Declination - distanc
above or below the
celestial equator



To measure distances around the bowl of the sky we use right ascension. The zero point is on the celestial equator. It is called the first point of Aries or γ. It is the place which the sun occupies in the sky on March 20 every year. It is the spring equinox. Right ascension is usually measured in hours and it is measured to the left of γ. This point, of course, appears to move around the earth just like a star would. To locate γ in the sky find the Great Square of Pegasus (see Lesson 10A, Section I, page 7). Follow the two stars on the east side of the Square south a distance about equal to that between the stars. You will come very close to γ:



We have now become acquainted with the celestial north pole (Polaris) and the celestial equator. Where does the ecliptic (the path of the sun among the stars) fit in the picture? There are two times during the year when the sun rises straight east and sets straight west. Thus, the sun is on the celestial equator two times a year. This means that the ecliptic crosses the celestial equator twice. Note that as the celestial equator turns about the axis to Polaris, the ecliptic wobbles up and down.

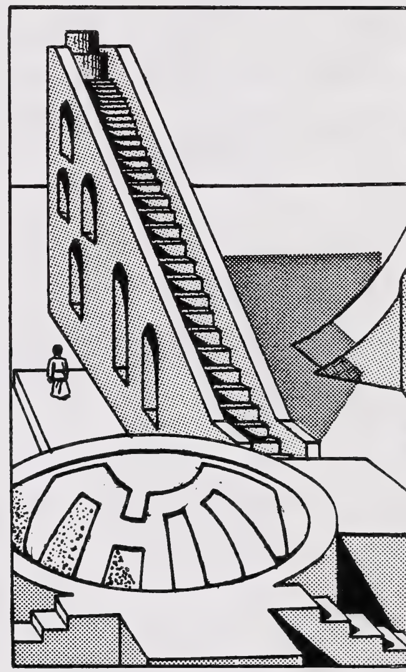


The photograph on page 20 shows a model of a celestial sphere. There is a ball at the centre to represent the earth. Study the photograph carefully, noting all of the parts that we have studied above.

Careful observations of the sun revealed to Indian astronomers that the equinoxes move through the heavens very slowly over the centuries. Indian astronomers were also able to calculate that the distance to the moon is $64\frac{1}{2}$ times the radius of the earth.

There were two important instruments in Indian astronomy - the gnomon and the armillary sphere.

In the 18th century an Indian astronomer, Jai Singh II, built a huge naked eye observatory. He realized that the bigger the instruments were the more accurate the measurements would be. Thus his gnomon was a huge triangle 17 m high. An arc was constructed under the triangle to measure the position of the gnomon's shadow. In additon Singh constructed a huge bowl on which were marked celestial latitude and longitude. A small pinhole in a metal disc formed the sun's image on the bowl's surface. The movement of this image could then be used to trace the sun's movement. Singh's purpose in building the observatory was to improve the Indian calendar, but the project was not finished.



Jai Singh's Observatory

The Mayas

The Mayas were an ancient Indian culture which occupied the Yucatan peninsula in Mexico up until the time of the Spanish conquest by Cortez in 1697. The Mayan culture had lasted for 3700 years.

The contributions of the Mayas did not have a direct influence on the development of modern astronomy. This was because of the isolation of the Mayas from the rest of the world. They are worth considering, however, if only because their accomplishments are so remarkable.

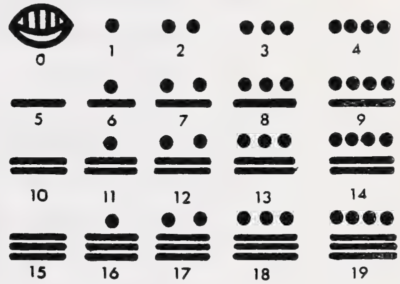
They are known for two outstanding achievements - a number system and a detailed and accurate calendar.

Their number system is unusual for two reasons. First they used a symbol for zero and they used it well before the time the Arabs began using zero. This was a real breakthrough for doing calculations. Imagine what it would be like to multiply with Roman numerals. Secondly, the number system was based on the number 20 (total number of fingers and toes) instead of 10.

The Mayas used a symbol for zero.

DCXXXVIII
× CDLXI
?

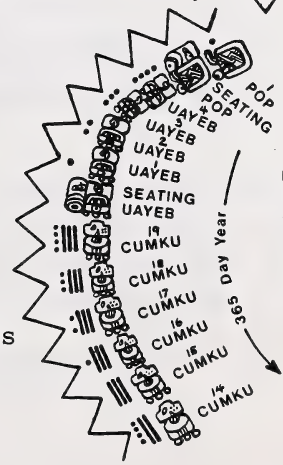
The Mayan number system was based on 20



The Mayan calendar was also quite unusual. The year was divided into 18 months of 20 days each with 5 extra days to complete the 365 day year. They also had a sacred year of 260 days. By using their calendar and number system they determined the orbit of Venus quite accurately. They also discovered that 81 lunations (months) = 2392 days. This gives 29.530 86 days per month - very close to the accepted value of 29.530 59 days per month. All this must have been done over many hundreds of years of patient observation for they did not have extremely accurate tools. Perhaps their pyramids, which served as combination temple-observatories, were their best tools.

For the Mayas the calendar almost became an object of worship. Their whole pattern and cycle of life was organized around the calendar. They celebrated this in their art, their architecture and their public life.

In addition to what we have just mentioned, the Mayas had names for Venus, the north star, the Pleiades, Scorpio, Gemini and Ursa Minor (the Little Dipper). They were especially interested in Venus because they believed that Venus, as a morning star, meant evil for them - thus they had some concern for predicting its behavior.



NAMES OF MONTHS

POP	YAXKIN	MAC
UO	MOL	KANKIN
ZIP	CH'EN	MUAN
ZOTZ	YAX	PAX
ZEC	ZAC	KAYAB
XUL	CEN	CUMKU
	SUYEB	

Because of their isolation the Mayan discoveries and inventions did not directly influence the history of astronomy. They do illustrate, however, what sorts of discoveries are possible through patient and extended observation of the movements of heavenly bodies.

Questions

1. The movements of the bodies visible in the sky were helpful for ancient man for two kinds of measurement. What were they?

   (a) latitude and longitude
   (b) distances to the sun and moon
   (c) time and direction
   (d) altitude and distances on the earth's surface ______

2. What was the dominant feature of the sky to an Egyptian astronomer-priest?

   (a) Sirius
   (b) the sun
   (c) the moon
   (d) the five visible planets ______

3. As a result of this dominant feature what measurement did the Egyptians know best?

   (a) length of the year
   (b) length of the day
   (c) length of the month
   (d) period of Venus ______

4. For the Mesopotamians the dominant feature of the sky was the motion of

   (a) the moon.
   (b) the sun.
   (c) Jupiter.
   (d) Venus. ______

5. What ancient observation would likely have contributed directly to the discovery of north as a direction?

   (a) the year-round visibility of the Big Dipper
   (b) the rising and setting of the sun
   (c) the path of the sun through the stars
   (d) the rising and setting of bright constellations like Orion ______

6. The Chinese placed a great deal of emphasis on

   (a) the rising and setting of the sun.
   (b) the path of the moon.
   (c) the altitude of stars above the horizon.
   (d) eclipses.
   (e) the north-south direction. ______

7. Briefly describe the difference between the Babylonians and the Egyptians in how they felt about the world.

____

____

____

____

____

____

____

8. Of the following groups of people: Chinese, Egyptian, Indian, and Mesopotamian name the one responsible for the following contributions.

   (a) armillary sphere, mechanical clock, equitorial co-ordinate system _______________

   (b) sundial, merkhet, 365 day year _______________

   (c) gnomon, armillary sphere, motion of equinoxes _______________

   (d) eclipse predictions, zodiac, gnomen _______________

9. The Mayas developed a very accurate and detailed calendar. Why did it not become a part of our present knowledge of astronomy?

____

____

____

How Can We Explain the Motions in the Heavens?

Up to this point we have become acquainted with some of the stars and constellations of the night sky. We have also learned of some of the motions of the sun, the planets and the moon. How can we understand these motions? A picture or machine or mechanical device that helps to explain something in the natural world is called a model. We are looking for a model that will help us understand and account for the various motions that we observe. A good model can be used not only for explaining motion but for predicting the position of a heavenly body in the future.

Models - explain and predict natural phenomena

The first people to seriously search for such models were the Greeks. But before we examine their contributions to astronomy let us recall some of the motions of heavenly bodies that we must account for:

1. The daily apparent rotation of the sky around the earth.
2. The monthly cycle of the moon's phases.
3. The slow motion eastward of the sun among the stars - one time around every year.
4. The movement of the sun from high up in the sky in summer to low in winter.
5. The uneven motion of the planets or wanderers through the sky against the background of the stars.
6. The loops that the planets appear to describe from time to time.
7. The change in brightness of the planets as they move through the skies. At opposition or inferior conjunction the plants appear brighter than near conjunction or superior conjunction.

Astronomical evidence that a model must explain

A good model will account well for all of these motions. Also, a good model will account for the motions in a reasonably simple way and it will agree reasonably well with the observed data.

The Greeks

Greek civilization came to a peak about 600 B.C. and stood on the shoulders of the civilizations like those of Egypt and Mesopotamia that had gone before. For example the Greeks got much of their geometry from Egypt and much of their astronomical knowledge and observations from the Assyrians and Babylonians. The Greeks for the most part were thinkers, rather than doers. They tended to look down upon the menial tasks of the hands but rather emphasized the mental activities of the intellect. Thus the Greeks made their main contributions in thinking about the world rather than observing it. There were of course the usual few exceptions. One late Greek astronomer made some excellent observations of a large number of stars. But the main emphasis was on ideas, so it is not surprising that the first notions about the earth being round and the earth moving came from the Greeks.

Greek civilization borrowed much from Mesopotamia and Egypt

Greeks - thinkers

Ideas from the Greeks:
- the earth is round
- the earth moves

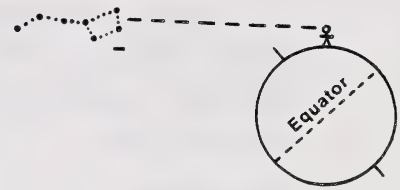
As we study each Greek thinker we shall try to describe and define what model he was using and what he was trying to account for with the model.

Tasks in this study:
- describe each model
- know what each model explains

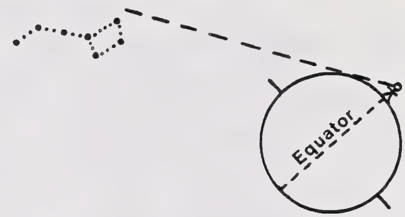
The earliest Greek astronomers of about 600 B.C. were those who had direct contact with the Babylonians and the Egyptians. One of them was Anaximander. In his day people thought of the earth as a flat disc with the sky arching overhead. Anaximander decided that this view could not be correct. First he knew that the Big Dipper never went below the horizon. But his teacher, Thales, who had visited Egypt said that from there, parts of the Dipper did actually go below the horizon. If the earth is flat, thought Anaximander, you should be able to see

Anaximander

the Big Dipper above the horizon anywhere. What model would account for the apparent shift of the Dipper's position? The only one he could think of is that the earth is round and if you go far enough south on this round surface it will eventually hide the Dipper from view.



Big Dipper Visible



Big Dipper Invisible

Questions

1. What observations did Anaximander require an explanation for?

____

____

____

Observation

2. What model did Anaximander propose to account for these observations?

____

Model

3. If we accept this model of the earth, what can we predict about the visibility of the Big Dipper if we go far enough south?

____

____

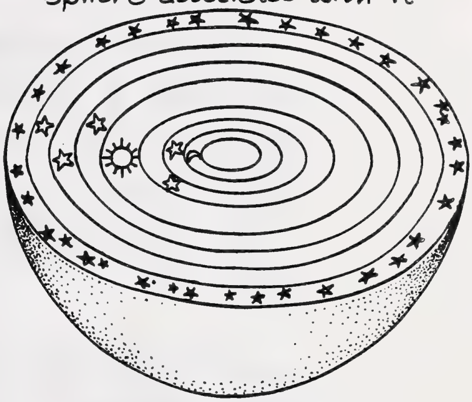
Prediction

Anaximander's model suggested that both the sky and the earth are spheres. This was difficult for most people at the time to accept. For one thing the earth does not look that way from a one-observer perspective. Secondly if the earth is round why don't we fall off? What keeps the oceans in place? These objections illustrate well that a model may often solve one problem but create others.

A model may solve some problems but introduce others

<u>Pythagoras</u> was another Greek who lived about 100 years after Anaximander. He was not content with just one sphere to represent the earth but he enriched Anaximander's model by assigning a sphere to each of the heavenly bodies. There was a set of nine spheres fitted inside each other — one each for the sun and moon, five for the five planets, one for the stars and an outermost sphere which provided the motive power for the others. As the spheres moved about within each other they produced sounds which only the most alert could hear. Here was born the idea of the "music of the spheres". Thus Pythagoras used both spherical geometry and music to try to explain the universe. Later a man called <u>Eudoxus</u> tried to improve upon Pythagoras' model by adding several more spheres for each planet. These spheres turned about various axes in various directions to give the motions of the planets. This was to account for many of the complications in the motions of the planets.

Pythagoras' model - each heavenly body has a sphere associated with it



Eudoxus - each planet has several spheres

The first man that we know of to suggest that the earth moves was <u>Philolaus</u>. He supposed that this motion took place around a central fire (not the sun). The central fire was invisible because it was always turned away from the Greece-side of the earth. This notion was quite fanciful but it did contain the important new idea about the motion of the earth.

Philolaus

<u>Aristotle</u> (384 B.C. - 322 B.C.) was the most famous of the ancient Greek philosophers. His ideas were held in high respect for hundreds of years even though many of them in the area of physics have since been superseded by more adequate conceptions. He did, however, propose an accurate explanation of the phases of the moon and of eclipses. These explanations depend on a number of ideas which were not common in that period. He proposed that the moon was a sphere which revolved around the earth so that it passed between the earth and the sun and that the moon shone, not by its own light, but by reflected sunlight.

Aristotle - a model that accounted for eclipses and phases of the moon

Aristotle also supported the idea that the earth was a sphere on the basis of the observation that the shadow of the earth during an eclipse is circular.

The full moon partially eclipsed by the earth's shadow

He also entertained the idea that the earth goes around the sun. But he rejected it because he argued that as the earth moved, the stars would change their apparent direction. He was not able to see that they did. Aristotle, of course, had no idea of how far it is to the nearest stars, nor for that matter, how far away the sun and moon are.

Today it is possible with a telescope to observe that the nearest stars do show slight changes in direction. The largest change is 1.5″ of arc or $\frac{1}{864\,000}$ of a circle.

For the most part the Greeks in this early period were thinkers, interested in ideas rather than practical skills or observation. Later in the period beginning about 250 B.C. a change began to take place. Euclid's geometry in a way combined the skills of thinking and doing. It would later prove very important as a tool for both observing and explaining the motions of the heavens.

Late Greek Period - more observation and practical skills.

Euclid (~ 300 B.C.)

Aristarchus of Samos lived during this period. He, like Philolaus, suggested that the earth might be in motion. In fact, he thought, you could explain the sky movements if you had the earth going around the sun once a year. This would explain the apparent motion of the sun through the stars. In addition, if you had the earth turning about its axis you would have a good way to explain the rising and setting of heavenly bodies once every day.

Aristarchus

Revolution and rotation of the earth

One objection to this is that if the earth moved, the stars should change their apparent directions from each other as seen from earth. To overcome this, Aristarchus proposed that the fixed stars were very far away and thus direction change is very small.

Objection

Though all three of these proposals are part of our present understandings of the universe, they were not accepted in Aristarchus' time. Gradually an earth-centered view of the universe won out and held sway for over 1500 years.

Questions

1. Match the following features of Aristarchus' model of the universe with the observations that each of these features explained.

   (a) The earth moves around the sun once a year.

   (b) The earth turns on its axis once a day.

   (c) The stars are very far away.

   _____ This explains the apparently stationary position of the stars.

   _____ This explains the daily rising and setting of heavenly bodies.

   _____ This explains the apparent motion of the sun among the stars.

2. Plato and Aristotle believed that the sphere of the stars turned around the earth once a day. On the basis of Aristarchus' model what would you predict about the motion of the stars?

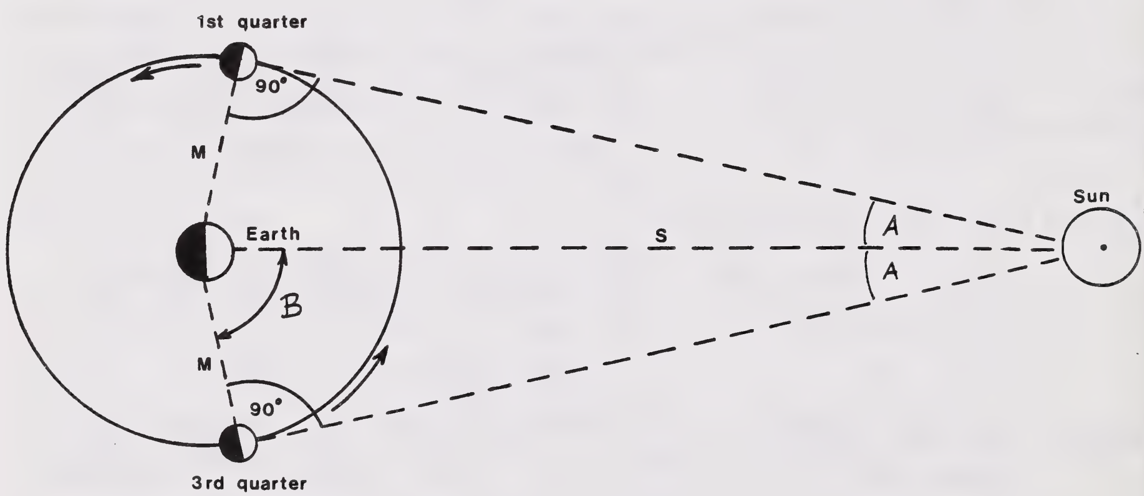
____

____

3. Name one of the motions listed on page 26 which Aristarchus' model does not yet explain.

____

Aristarchus also made the first objective measurement of heavenly bodies. He did this by observing how long it took the moon to move from first quarter to third quarter. In effect he was measuring twice the angle A shown in the figure below.

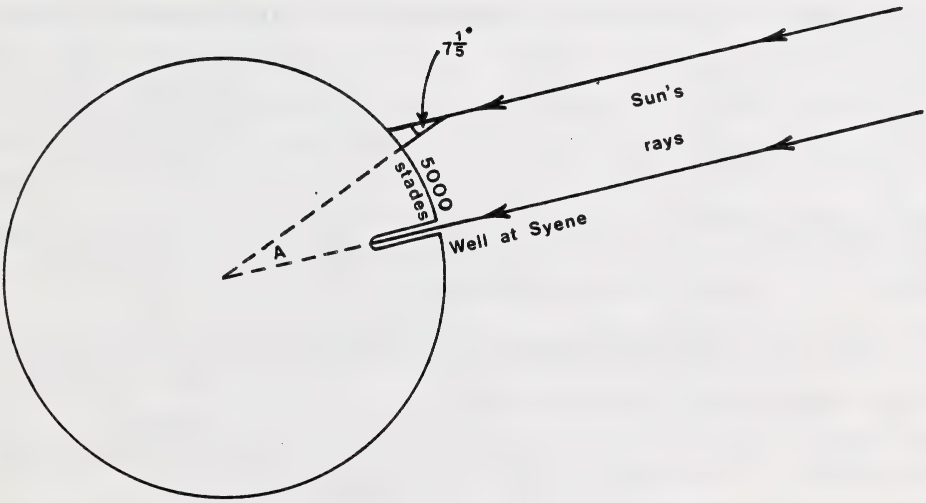


Aristarchus' Method for Measuring Distances to the Sun and Moon.

If you know the two angles of a triangle you then are able to compare the lengths of the sides. This is what Aristarchus did. As it turned out there were quite a few errors in his measurements.

Angle A is very small (about $\frac{1}{7}°$), and difficult to measure. He showed, however, that this calculation was a possible way of measuring distances.

Another Greek who lived shortly after Aristarchus was Eratosthenes who was the first man to measure the circumference of the earth. He did this by noting that at noon on June 21 at Syene in South Egypt the sun shone directly down a deep well. At the same time in Alexandria in northern Egypt the sun cast a shadow $7\frac{1}{5}°$ from the vertical. He assumed the sun's rays were parallel. This is valid if the sun is very far away.



Eratosthenes' Measurement of the Earth

The distance between Syene and Alexandria is therefore $\frac{7\frac{1}{5}°}{360°} = \frac{1}{50}$ of the total distance around the earth. The distance around the earth by Eratosthenes' calculation was therefore 50 × 5000 stades = 250 000 stades.

We are not sure of the size of the stade that Eratosthenes used. His final result may have been from less than 1% error to as much as 17% error.

Lesson Summary

Astronomy is first of all an activity of people with personalities, skills and ideas. Many ancient astronomers had to have patience, long training and devoted interest to learn what they did about the heavens. Some ancient astronomers were held in high honor, as the astronomer priests of Babylon and the astrologers of China. Others had to have rare courage to do something that was quite unpopular at the time. Some of them were geniuses - others simply careful and patient observers. But one thing they all had in common was respect for and overwhelming interest in the movements in the skies and what they meant. They share that with us who in the twentieth century are trying to understand more of what they learned. We are dependent on them because they began and gradually increased the observations and knowledge that are available to us today.

Many kinds of motion were observed - the daily apparent rotation of the sun, moon and stars around the earth, the path of the sun through the stars in the course of the year, the irregular motions of the planets, the shift of the First Point of Aries (spring equinox) through the centuries, the eighteen-year pattern of the moon's motion and its relation to eclipses. They not only observed these motions, but also found patterns in them.

The astrolabe is an ancient instrument that can be used as a model to represent the motions of the stars, sun and planets. It is the projection of a sphere on a flat surface.

The Egyptians made their greatest contribution in observing the sun since the sun dominates the sky in Egypt. They used gnomons and sun shadows to observe the sun's motions.

The Mesopotamians focussed attention on the motions of the moon and the planets. The month became the standard of time.

The Chinese gave us the equatorial system of coordinates and the use of the meridian for observing stars. This system uses the celestial equator as a baseline for measuring declination in degrees and the First Point of Aries (spring equinox) as the starting point for measuring right ascension in hours.

The Indian astronomers observed the precession of the equinoxes (the slow movement of the equinoxes through the sky over centuries).

The Mayas used a symbol for zero and made some very accurate observations of the planet Venus. They also designed a very accurate calendar.

The Greeks were the first to set forth models for understanding the motions observed in the sky. Some proposed a round earth, others the rotation and revolution of the earth. The early Greeks emphasized thinking as opposed to practical observations and skills.

Questions

1. For the Egyptians the most important heavenly body was
   (a) the moon.
   (b) Venus.
   (c) the sun.
   (d) Mercury. ______

2. In Mesopotamia, time was measured primarily by
   (a) Venus and Mars.
   (b) the moon.
   (c) precession of the equinoxes.
   (d) the sun. ______

3. For Egyptian time keeping, the most important star was
   (a) Venus.
   (b) Capella.
   (c) Polaris.
   (d) Sirius. ______

4. The most important single event in the Egyptian year is
   (a) the flooding of the Nile.
   (b) the sun entering the spring equinox.
   (c) the eclipse of the moon.
   (d) the time of the shortest sundial shadow. ______

5. A major timekeeping problem for all ancient peoples but especially the Mesopotamians was
   (a) the uneven length of the year.
   (b) the uneven number of months in a year.
   (c) the apparent speed change of the sun through the stars throughout the year.
   (d) irregular motions of the planets. ______

6. The number system that we use in measuring angles and time came from
   (a) the Egyptians.
   (b) the Arabs.
   (c) the Babylonians.
   (d) the Chinese. ______

7. The equatorial system of locating stars comes from measuring

   (a) a star's passage across the meridian.

   (b) a star's time of setting or rising.

   (c) a star's disappearance behind the sun.

   (d) the occultation (eclipse) of a star by the moon. ______

8. Which of the following is a Chinese contribution to modern astronomy?

   (a) the gnomon

   (b) the sundial

   (c) the merkhet

   (d) the mechanical clock ______

9. A most important contribution of the Greeks to astronomy was in

   (a) mathematics.

   (b) astronomical instruments.

   (c) observatories.

   (d) astronomical measurements. ______

10. Why did men like Aristotle reject the idea of the motion of the earth?

   ____

   ____

   ____

   ____

11. Match the following discovery (or model or idea) with the man who was first associated with it (do as many as you can without referring to the lesson notes):

________	earth's circumference	A.	Plato
________	spherical earth	B.	Philolaus
________	music of the spheres	C.	Aristotle
________	motion of the earth	D.	Thales
________	sun-centered universe	E.	Pythagoras
________	complete geometry	F.	Anaximander
________	phase of the moon	G.	Euclid
		H.	Aristarchus
		I.	Eratosthenes

12. In the winter, constellations not seen in the summer sky become visible. Why is this so?

____

____

13. How many minutes does it take for the sun to appear to move 1° through the sky? (Remember that the sun appears to move through 360° in 24 h).

14. How many degrees does the moon move through in one day? (The moon completes one revolution around the earth against the background of the stars in 27.13 days.)

End of Lesson 11A

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Elective A
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FROM PTOLEMY TO GALILEO

An Ancient Greek Astronomer

Hipparchus (~ 130 B.C.)

The greatest observational astronomer of ancient Greece was Hipparchus. He was in one sense the first truly modern astronomical observer. When he was a young man he observed a very unusual sight. A star appeared where none had been before. What he saw must have been what we today call a nova, or star explosion. Hipparchus may have checked some of the records of the past to see if this star had been seen in earlier ages. This search must have left him dissatisfied because he decided that he would make a catalogue of the stars. In order to locate them he carefully measured celestial latitude and longitude for 850 stars. To identify them even better he classified the stars according to brightness or magnitude. There were six magnitudes in all. We still use this method in modern astronomy (see Lesson 10A, page 25).

A stimulus for Hipparchus' keen interest in observation

Star catalogue

Hipparchus also searched through records of the past to try to detect slow changes in the heavens that could not be seen in one man's lifetime. Out of this study he discovered that the north celestial pole is slowly moving in a circle through the sky. He also made observations that he himself could not use but which might be used by later astronomers. He gave special attention to observing the planets.

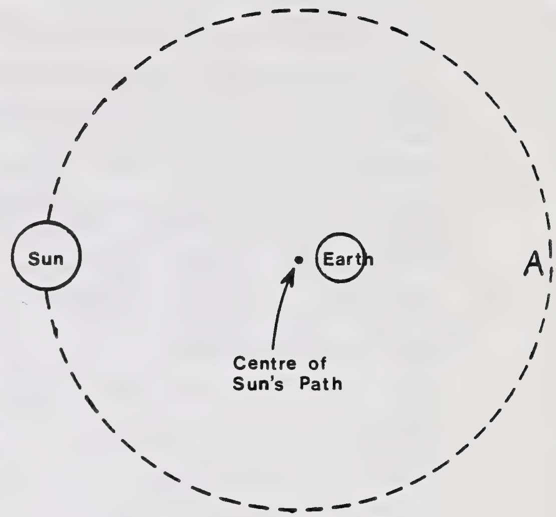
Movement of the celestial North Pole is the same phenomenon as the precession of the equinoxes

To make it easier to work with the "skinny triangles" of astronomy, Hipparchus either developed or invented some elementary forms of trigonometry. This is the branch of mathematics which makes it possible to solve triangles by using tables and calculations instead of diagrams.

Trigonometry

Finally Hipparchus designed his own model to explain the motions of the heavens. He had observed that the sun appears to move faster through the sky at one time of year than another. He also noted that the diameter of the sun changed slightly throughout the year. To account for this he suggested that the sun moved around the earth in an eccentric path.

This means that the sun moves in a circle whose centre is not at the earth but slightly to one side. When the sun is closest to the earth at A, it appears largest. Also when it is closest to the earth, it moves the fastest. He was also able to predict an eclipse of the moon to within about an hour of the time it actually occurred.



Hipparchus' Model

Hipparchus' model worked well for the sun, less well for the moon, but not at all for Mars! This must have disturbed him so much that he gave up trying to explain the planet's motions. Instead he simply tried to make accurate observations for future astronomers. His labors seemed only to make it less, not more, possible to explain the workings of the universe.

Hipparchus' model worked poorly for the planets

Hipparchus' observations and ideas served as a solid base for a later astronomer whose ideas and models were to dominate astronomy for hundreds of years. Ptolemy (80?-160?A.D.) brought together previous observations and formulated a new model of the earth-centred universe. There is some question about whether Ptolemy really did accomplish all that is ascribed to him. Some suggest that a good bit of fraud was involved. Yet the model that is attributed to him was the standard understanding of the motions of the heavens for many years.

Ptolemy's model was based on Hipparchus'

Ptolemy's biggest contribution was a book of 13 volumes called the Almagest (Arabic meaning:"Great Book"). In this book he explores the whole range of astronomy of his day. He ends the book by proposing a model to explain the motions of the planets. This book is very important because it was the last word in astronomy for 1400 years up until about 1500 A.D.

The Almagest had as its original title Megistē Syntaxis (Greek - The Great Arrangement)

Ptolemy relied a great deal on previous observers, especially Hipparchus. He added another 300 stars to Hipparchus' list of 850. He is purported to have made many observations of his own especially with an instrument called the armillary astrolabe. With this instrument he discovered two very small variations in the moon's motion called evection and nutation.

Ptolemy purportedly discovered evection and nutation in the moon's motion

The most outstanding part of Ptolemy's work was his mathematics. He improved the trigonometry of the day to use in his model of the universe. The task was to fit the tables of observation into a set of circles that would explain and predict the motions of the planets. The idea that circles must be used came from an earlier time in Greece, the time of Plato and Aristotle who believed that the circle is the most perfect and pleasing shape. To their minds, the heavens were bound to show this perfection. The challenge to any astronomer was to find what combination of perfect circles could reproduce and predict the observed motions of the heavenly bodies.

Ptolemy used the mathematics of circles

Assumption: The circle is the most perfect and pleasing shape.
Conclusion: The motions of heavenly bodies must be described with circles

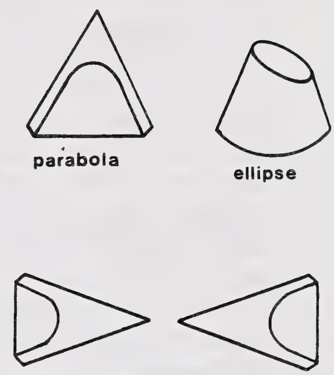
Ptolemy began his work with three major ideas: the heavens are a sphere; the earth is a sphere; and the earth is at rest at the centre of the universe. He rejected Aristarchus' idea that the earth goes around the sun for several reasons: all heavy objects tend to move to the centre of the earth; if the earth moved, one should be able to see its effects on objects moving through the air (instead of falling straight down they should fall sideways); and if the earth moved, one should be able to see the stars change their positions (they do not appear to do so).

Three major ideas for Ptolemy's model:

1. *The heavens form a sphere.*
2. *The earth is a sphere.*
3. *The earth rests at the centre of the universe.*

Problem - the varying apparent motions of the planets and the sun

One of the major problems in explaining the motions of the heavens is the uneven way in which the planets and the sun appear to move around the earth. The sun appears to move through the stars faster at some times of the year than at others. Hipparchus explained this by using an eccentric. This worked out quite well for the sun but not for the planets. The planets not only appear to move at different speeds, they also appear to move backwards in the sky. Hipparchus did not try to explain this but Ptolemy did. He borrowed an idea from an earlier astronomer Apollonius (about 200 B.C.) who first used the terms parabola, ellipse and hyperbola to describe the conic sections. These are called conic sections because they can be formed by cutting a cone in a particular way.

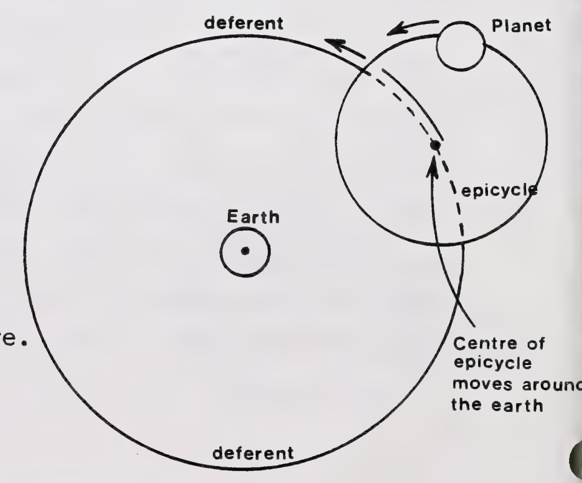


Conic Sections

Apollonius suggested two ways of explaining a planet's motion. One was to use the eccentric orbit (see page 2, Lesson 12A). The other explanation used an epicycle and deferent. By the latter explanation, a planet moved in a small circle called an epicycle. The centre of this small circle then moved around in a larger circle (the deferent) with the earth at its centre.

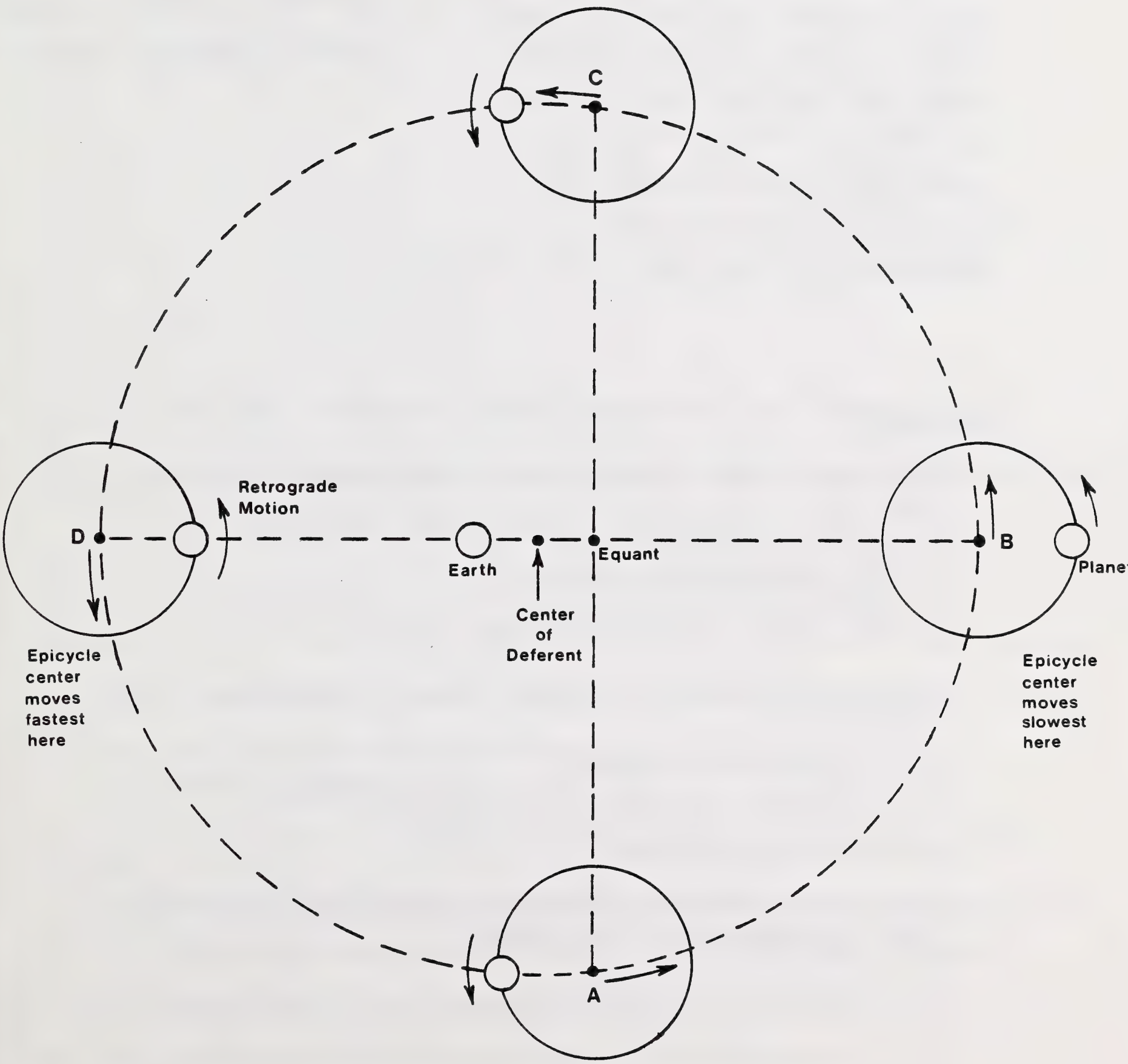
In many ways this model worked well because it helped explain two observed facts: (1) the apparent backward (retrograde) motion of a planet; (2) the change in brightness of a planet as it moves along its orbit.

But even this was not good enough. It could not predict future positions of the planet accurately. Ptolemy had to make a further change. He placed the deferent centre to one side of the earth (thus the deferent became an eccentric).



Apollonius' Model

He also made the centre of the epicycle move at a constant speed around a point called the equant (and not around the centre of the deferent). If you think this is becoming complicated, you are right. It is! Later we shall see that this is one reason why a new and very different model was needed to account for heavenly motions. Studying the diagram below carefully may help to make Ptolemy's model easier to understand.



Ptolemy's Model of a Planet's Motion

By saying that the epicycle moves with constant speed about the equant we mean that the epicycle takes the same amount of time to go from A to B as it does from D to A.

It is interesting to note that Ptolemy began with two simple ideas - the earth was at the centre of things and the planets moved in perfect circles. His model included perfect circles, to be sure, but the earth was no longer quite at the centre and there were now a number of imaginary points moving about other imaginary points. Yet this model was the best available until about 450 years ago, simply because it helped to explain more observations than any other.

Ptolemy's model included perfect circles but also needed imaginary points

Questions

1. What was the key feature of Hipparchus' model of the orbit of a planet?

   (a) The orbit was an ellipse.
   (b) The orbit was an eccentric.
   (c) The orbit was an epicycle.
   (d) The orbit was an earth-centred circle. ______

2. What made Ptolemy's model of a planet's orbit different from Hipparchus'?

   (a) It involved an eccentric.
   (b) It took the earth away from the orbit's centre.
   (c) It made the earth go around the sun.
   (d) It included epicycles. ______

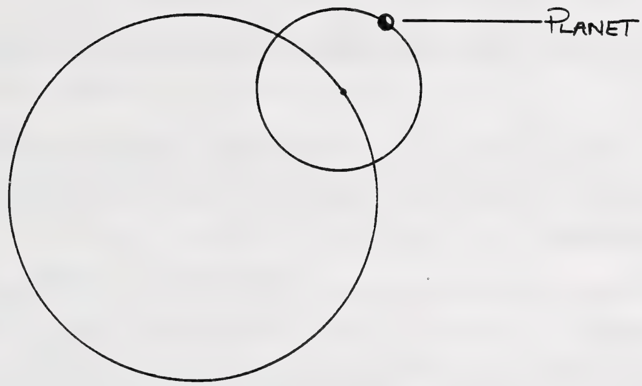
3. List three observations about planets and their motions which must be explained by a good model.

   (a) ______________________________

   (b) ______________________________

   (c) ______________________________

4. Label the epicycle on the diagram.



5. (a) Which model was simpler, Hipparchus' or Ptolemy's?

____

(b) Which model was considered more useful? Why?

____

____

____

6. Why did Hipparchus and Ptolemy use only circles to explain planetary motion?

____

____

7. What is one weakness of Ptolemy's model of planetary motion?

____

Though it was not perfect Ptolemy's model helped to explain a number of things:

1. It predicted reasonably well the positions of sun, moon and planets.

2. It explained why the fixed stars do not shift in position throughout the year.

3. It agreed well with Greek philosophy regarding perfection of circles and with the ideas of natural place (the centre of the earth is the natural place for earthly bodies, the sky for heavenly bodies) and natural motion.

4. It made sense because the sun, moon and stars appear to revolve around us.

5. It made the immovable solid earth (which all of us experience as solid and immovable) the centre of the universe.

It is not surprising that Ptolemy's model lasted for 1500 years.

Several hundred years after Ptolemy's death the Roman Empire began to crumble. Eventually tribes from Europe conquered Rome and the ancient world fell into disrepair. The Romans had not been great astronomers or mathematicians and the barbarian tribes which now were in control were even less so.

Thus it fell to the Arabic peoples to preserve and continue the learning which had begun in Greece and in the ancient civilizations of Mesopotamia and Egypt.

The contributions of the Arabs are considerable. In mathematics they developed the concepts of algebra (which is an Arabic word). They invented sines, cosines and tangents used in trigonometry. It is from them that we got the symbols for our number system, Arabic numerals. In astronomy they studied the works of the Greeks, especially Ptolemy, built observatories and invented a number of astronomical instruments. They made many careful observations as a result. In addition, the learning which the Arabs fostered was passed on to Europe through the schools and universities which the Arabs founded, especially the University of Cordoba in Spain. Many European students came to study there.

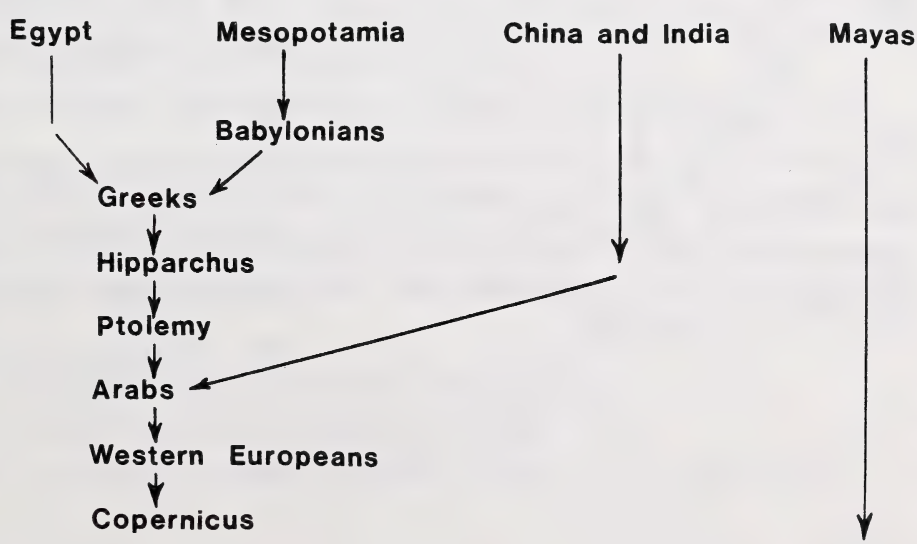
The Muslim religion provided much stimulus for astronomical studies. Astronomy was considered the most noble and beautiful study possible, because it focused on the glory of Allah in his construction of the universe. Practically, astronomy was useful in determining the sacred month of Ramadan, the hours of prayer and the direction of the sacred city, Mecca. In many of their observatories the Arabs set about verifying and correcting Ptolemy's tables in addition to setting up their own.

The Arabs also used astronomy in navigation. They were the first "northerners" to observe the Magellanic Clouds which they were able to see on the way to Madagascar. (The Magellanic Clouds are one of two nebula visible to the naked eye and are visible primarily in the Southern Hemisphere).

The Arabs contributed much in the use of instruments. They used a Chaldean hemispherical gnomon to make some observations of the planets. These observations challenged parts of Aristotle's thinking about the motions of heavenly bodies. They became very skilled and wrote books about it.

Thus, though from 200 A.D. to 1500 A.D. there were no new developments in the understanding of the motions of heavenly bodies, the Arabs preserved theories from the ancient world and contributed much to the practical uses of astronomy.

It is interesting at this point to note the flow of astronomical activity as it has come to us from the ancient world. We can illustrate it as follows:



Astronomy and Clocks

We have been talking about models of the universe. By that term we have meant mathematical and geometrical models. How would one make a mechanical model of the universe? In one way that is almost the same as asking "How do you make a clock?" For the universe appears to us as a complex timepiece. The period between one sunrise and the next sunrise is one day. The period between two full moons is a month. The period from the time when the sun is highest in the sky at noon to the next time it is highest at noon is the year. The planets are more irregular, and so there is no common time period which they define; nevertheless they move with some regularity. To make a model of the universe we need to be able to approximate these motions.

The first attempts at this were sundials especially the hemispherical sundials in which the sun's image moved across a hemisphere. Water-clocks were used to extend the usefulness of sundials in timekeeping.

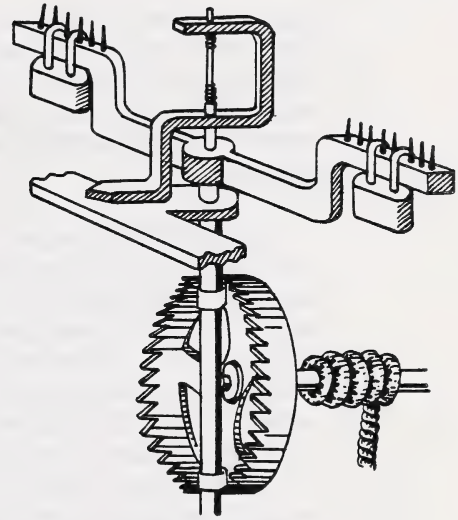
Then, about 700 A.D. in China, someone invented the first mechanical clock. It was driven by waterpower and was in fact an imitator of heavenly motions. This huge mechanism was operated by a waterwheel which advanced by one notch as each cup filled with water. The clock not only told time by means of figures which announced the time, it also turned an armillary sphere and a celestial globe. The armillary sphere was used for observations much like a modern telescope. Thus, this was the first clock-drive mechanism similar to those used on modern telescopes.

The first mechanical clocks began to appear in Europe about A.D. 1300. They measured time by using a verge and foliot mechanism. In many ways this is similar to the balance wheel of a modern wristwatch, though with some differences as well.

The Chinese waterclock was made using a water wheel with small buckets evenly spaced along its circumference. The wheel turned a series of gears that were attached to the celestial globe and the armillary sphere

The pendulum clock (which we are most acquainted with in the form of grandfather clocks or cuckoo clocks) was designed by Christian Huygens in 1657. This markedly improved time-keeping.

The invention of the mechanical clock had two very interesting effects. Up until this period, time had been measured by sundials on which hour markings were evenly spaced. The sun's shadow, however, does not pass these markings in equal times throughout the day. Thus the length of the hour changed throughout the day. It was not until mechanical clocks were invented that people began to think of time as flowing evenly. Hours of equal length began to be used. This prepared the way for much greater accuracy of observation. Mechanical clocks also kept alive the interest in the motions of the heavenly bodies even though observational astronomy was for many centuries no more advanced than in Ptolemy's time.



The invention of mechanical clocks encouraged people to conceive of time as flowing in even units

Shaking the Earth Loose - Copernicus

The Renaissance began in Italy in the 1400's. It was a revival of interest in the study of man's art and culture, especially that of the ancient world. Much of the ancient learning had been preserved by Arab scholars and now became available in the original texts in Latin and Greek.

These texts included works on astronomy. It was in this new age that Nicolas Copernicus lived. It was an age that encouraged new ideas yet also had difficulty changing some older cherished ones.

Copernicus was the youngest child in a family of four, born of a wealthy mother and a father who was a community leader (magistrate) and merchant in Torun, Poland.

The Renaissance

His uncle was a bishop in the Polish church. This fact later was of some importance to Copernicus because he was to receive an appointment in the church, which gave him some of the freedom he needed to study astronomy.

Copernicus began his education in canon law (the laws of the church). Later he studied medicine but all the while he pursued his interest in astronomy. Between his duties at the cathedral where he was stationed he had opportunity to make observations from his turret observatory. Copernicus used not only his own observations but also those of the Greeks and Arabs, some of which were quite unreliable. He often gave himself a lot of trouble by accepting these erroneous observations as accurate.

Study in canon law

Medicine

Copernicus relied on old, inaccurate observati

Copernicus was asked at one point to help set the calendar straight. He replied that he could not do so until the laws governing the sun's and moon's motions became clearer. That was in 1514 and it was not until 1543 that Copernicus published his book on the new astronomy. Later it would be used to produce the new calendar proposed by Pope Gregory in 1582 — the one we still use today.

Gregorian calendar 1582

Advances in astronomy as well as in other areas of science, have come about as much through careful thinking as through improved observation. Such was true of Copernicus. His observations are worth little today, but it was his thinking that helped to create a turning point for science that ushered in a new age.

Copernicus' thinking much more valuable than his observations

Copernicus wrote a book "On the Revolutions of the Celestial Orbs..." to present his new understandings of the universe. Being a cautious man he did not set it forth for publication until just before his death in 1543. There were six parts in the book:

"On the Revolutions of the Celestial Orbs" 1543

Book I - Description of the new picture of the universe with the sun at the centre (including an explanation of the seasons) - also several chapters on trigonometry.

Contents of Copernicus' book

Book II - Trigonometry applied to the heavens, star catalogue

Book III - The earth's motion

Book IV - The moon's motion

Books V and VI - The planets' motions

Difficulty with the equant

The contents of this book show that Copernicus had studied Ptolemy very carefully. One thing about Ptolemy's model that Copernicus could not accept was the equant, that imaginary point about which the planet's epicycle travelled with constant speed. There was something too unreal, too arbitrary about it. Certainly, Copernicus thought, there must be a simpler way to make the model. No doubt he had read about some of the ancient Greeks who had suggested that the earth moves around the sun and turns on its axis once a day. He began to see that if these two were put together you would have a marvelously simple explanation of many observations. Why does the whole sky appear to move around the earth once every 24 h? Because the earth itself is turning under the sky. Why do the planets' motions appear to change from time to time and even reverse? Because the earth itself is moving, making the planets appear to change positions against the background of the stars. Thus many of the supposed motions of the heavens could be simply accounted for by motions of the earth.

The beginnings of Copernicus' model

Motions of the earth?

But getting the earth to move is not an easy matter even if you can make such calculations.

Copernicus supposed that not only the earth but other planets too revolved around the sun. By using this new understanding he was able to calculate the distances of the planets from the sun in comparison to the earths distance. He also calculated how long it took each planet to go around the sun.

Questions

1. What did Copernicus find objectionable in Ptolemy's model of the solar system?

   (a) the equant

   (b) the epicycles

   (c) the eccentric path for the planets

   (d) the use of circles ______

2. Why did the Arabs become the inheritors of the astronomy from Greece?

   (a) They were more closely related to the Greeks than any other group.

   (b) Their religion and philosophy of life encouraged seeking knowledge of the heavens and information about times and seasons.

   (c) They were the first conquerors of Greece.

   (d) They had better access than the Romans did to the knowledge and learning of Greece. ______

3. What new understanding about time came about through the invention of the mechanical clock?

   ____

4. What is Copernicus best known for?

   (a) His careful observations.

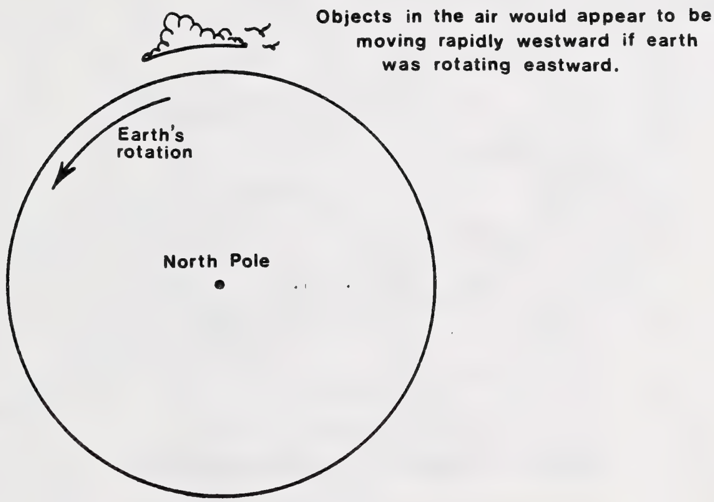
   (b) His new thought about the universe.

   (c) His courageous and public questioning of old models.

   (d) His understanding of Ptolemy. ______

It is not an easy matter to show that the earth moves. People in Copernicus' day raised a number of objections. If the earth moves, some said, anything floating in the air would be left behind and would appear to be moving west at a furious speed.

Objections to a moving earth



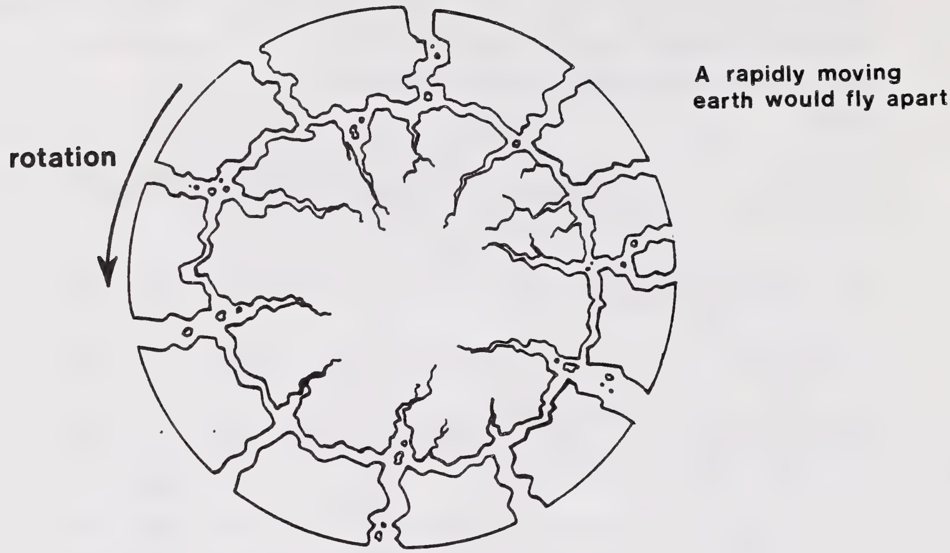
One Objection to a Rotating Earth

Copernicus replied that the air and objects suspended in it may in fact move along with the earth. We might respond by asking "Well, what is it that doesn't move then?" An answer to this would bring us head on into one of the controversies of science in the 19th century.

If the earth moves what does not move?

The controversy centred around the supposed existence of a motionless fluid called the ether

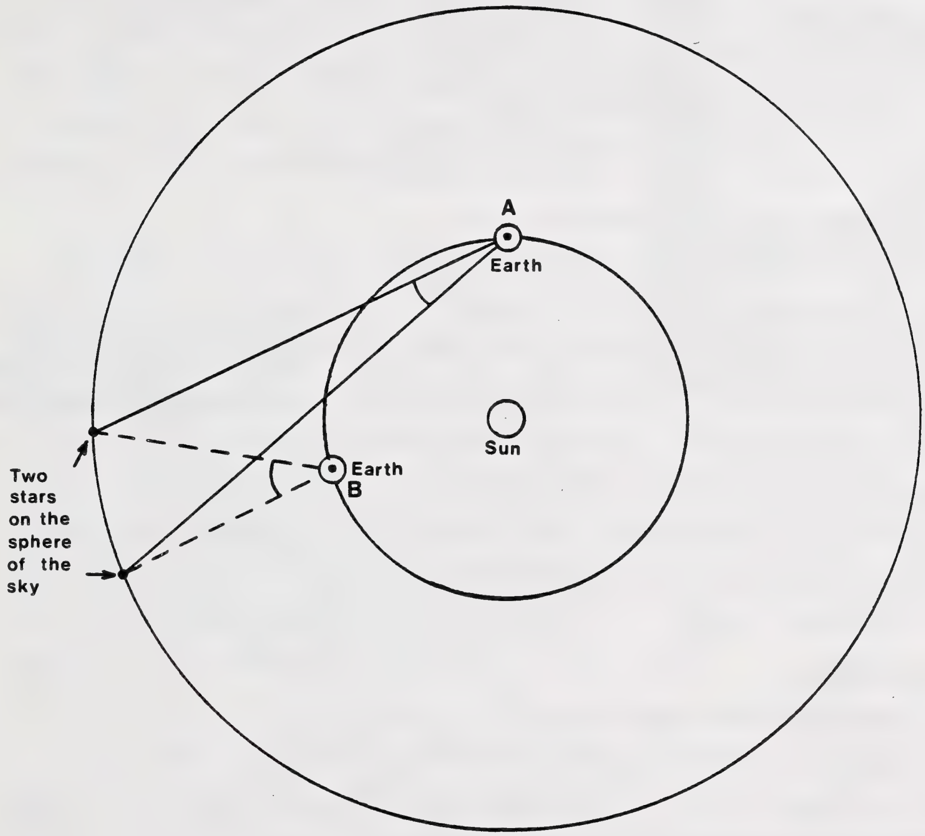
If the earth is turning so fast, others objected, it would be torn to pieces.



Another Objection to a Rotating Earth

Copernicus replied that if the sky turns, that is even more of a problem. The edge of the sky would be moving much more rapidly than the earth. Surely it would be in much greater danger of falling apart.

Still another objection is that if the earth moves, then the stars should appear to change their positions. They do not appear to do so.



Parallax of Stars Should Result if the Earth is Moving (The Viewing Angle is Greater at B than at A). The Angles Become Nearly Equal if the Stars Are Very Distant

Copernicus replied, as did some of the Greeks before him, that if the stars are very far away we would not notice their shift of position or parallax. This objection proved to be the most difficult to answer. For even if the stars are far away there must still be some very small change in their positions. As instruments become better we should be able to observe the change. For several hundred years no such change was observed even with telescopes.

Parallax could not be observed. How then could the earth be moving?

Still another objection to Copernicus is that if one accepted his sun-centred view it would mean that one would have to reject Aristotle. It would be unwise to quickly reject the authority of someone who had held so much authority for so long, especially since his thinking provided so much of the support for the theology of men like St. Thomas Aquinas.

Reject Aristotle?

In spite of these objections, the simplicity of Copernicus' model quickly appealed to many mathematicians of his day. Yet Copernicus did not really simplify Ptolemy very much. He still retained the eccentrics and epicycles though the sun was now at or near the centre, not the earth. One needed just as many calculations for Copernicus' model as for Ptolemy's model. It remained for a combination of a very careful observer and an outstanding astronomer-mathematician to discover an even better model.

Copernicus' model - only a slight improvement in simplicity over Ptolemy

Tycho Brahe

Copernicus had some trouble with his model partly because he had unreliable observations to depend on. Just three years after Copernicus died, a man who was to do something about this problem was born. Tycho Brahe (1546-1601) became interested in the stars at an early age. There were two events that propelled him into a full-fledged program of astronomical observation. One night there was a conjunction (very close approach) of Jupiter and Saturn. The tables available at the time predicted this conjunction a month later than it came. Then in 1572, a new star (a supernova), brighter than Venus, appeared in the sky near the constellation Cassiopeia. It was bright enough to be visible in daytime. As a result of these two events Brahe resolved to make accurate observations of the stars and planets. Even with crude instruments he had found inaccuracies in the tables. He resolved now to develop better instruments to make it possible to produce better tables

Brahe - Danish

Conjunction of Saturn and Jupiter

A supernova

and to study more precisely the position of stars, both new and old. He realized immediately that this would require very large instruments. He built first a quadrant with a 5.5 m radius. On this instrument 90° were distributed along 9 m, an average of 10 cm per degree. One minute of arc was represented by about 1.6 mm.

Observations with quadrant on meridian

Soon he was invited to set up an observatory on the island of Hven near Denmark by the Danish Court. Here he constructed an observatory with 27 different kinds of instruments. Among them was a celestial globe and a quadrant inscribed in a wall that ran directly north and south. On this quadrant he could determine the altitude of heavenly bodies when they crossed the meridian, the time of the night when they were highest in the sky. With this device he was able to measure the length of the year to within several seconds of the presently accepted measurement.

First new set of complete observations since Hipparchus

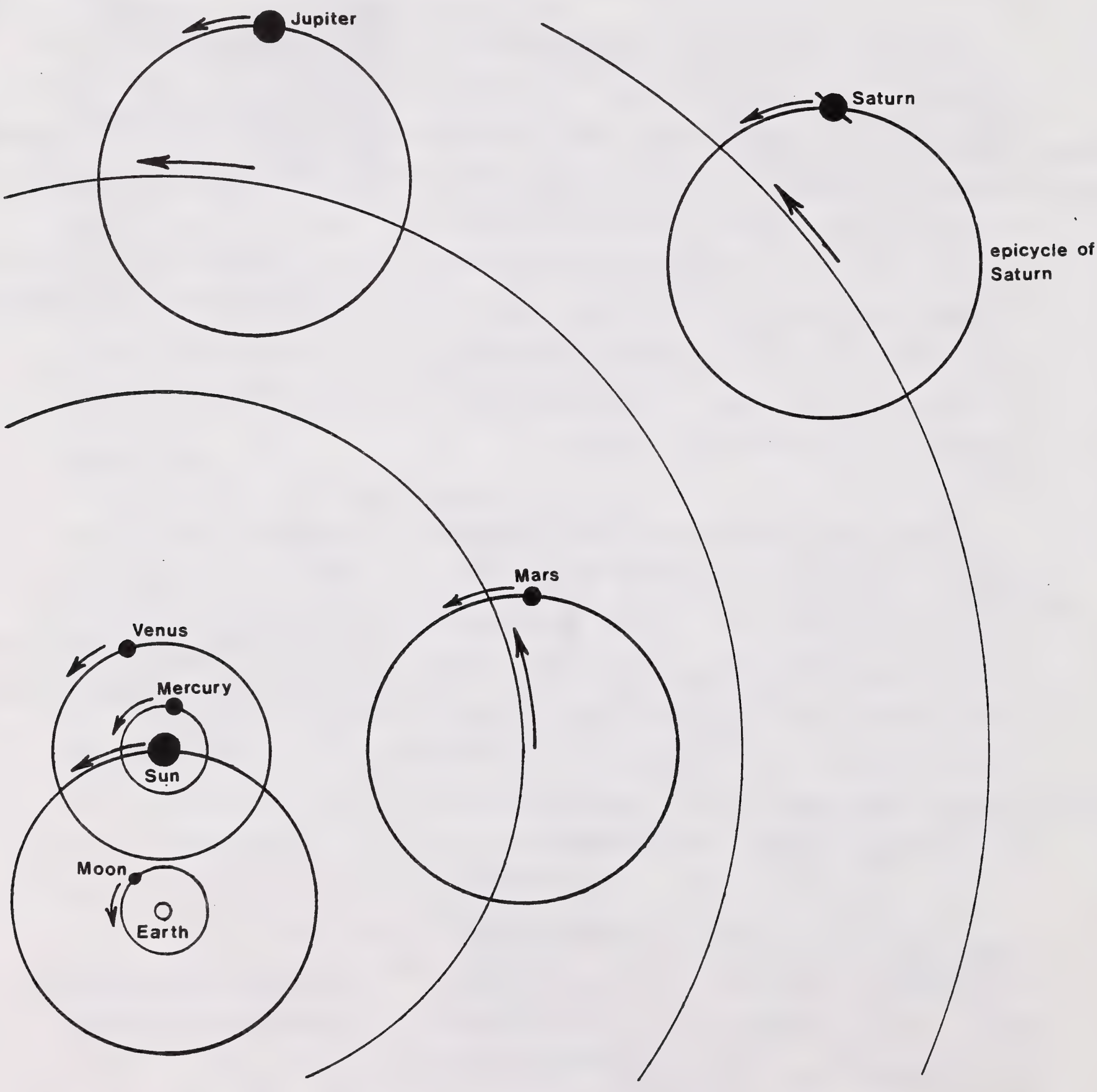
With these instruments Tycho Brahe patiently measured the positions of 777 stars. For each of these he averaged about 15 observations. It was the first time since Hipparchus, 1700 years earlier, that a completely new set of observations had been made and it took 14 years to do it. These precise observations made a very accurate set of data for planetary motion possible and provided some solid foundations for modern astronomy.

Brahe rejected sun-centred universe

It is worth noting that Brahe did not accept Copernicus' sun-centred universe. According to Aristotle, a moving object could be kept moving only by applying a continual force. Brahe could not see how the sluggish earth could move. Also, in his accurate observations he could find no evidence of parallax.

Yet he saw the advantage and simplicity of Copernicus' model. Then one day he had an idea that could accommodate both of these factors. Why could not the sun go around the earth while the other planets go around the sun? In this way Copernicus' simple solar system could be combined with a central earth. Brahe believed that he had found the best model of all to explain the motions of the heavens.

Brahe's idea



Tycho Brahe's Model of the Sun, Moon and Planets

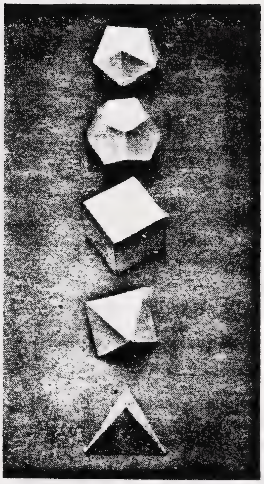
Brahe was a very unusual and colorful man. Along with his observatory in Hven he built a luxurious palace and grounds where he lived royally for many years. He was, however, a bit harsh and made enemies easily. When the king, who had invited Brahe to this island, died, Brahe had to go into exile. Eventually he died there, concerned to the end about whether his work had been in vain. But he need not have feared, for just over a year before his death he took on an assistant named Johannes Kepler. Rarely has such a combination of two men, one a precise and careful observer, the other an outstanding mathematician, produced such fruitful results.

Brahe's exile

Johannes Kepler

Kepler was a frail sort of man, very devout, very dedicated to the task of discovering a perfect explanation for the motions of the heavens. By the time he joined Brahe he had already done much thinking about astronomy. In fact he had written a book in which he set forth a model for the solar system using the five regular solids. Between each of the spheres representing planet positions was inserted one of the regular solids. Although this happens to fit quite well the five planets that Kepler knew about, it has little usefulness in predicting the positions of the nine planets that we now know.

Kepler - born in 1571 in the state of Württemberg, Germany



The next task Kepler set for himself was one that had baffled Copernicus. How can you account for the orbit of Mars? Copernicus simply could not fit it into a circle. As it turns out, Mars is a good sample for investigation of planetary motion. At Kepler's time there were too few observations of Mercury available, Venus proved to have a nearly circular orbit and Jupiter and Saturn moved too slowly for a number of observations to be obtained. Mars moved quite rapidly and had an orbit irregular (that is departing from a circle) enough to make it interesting.

How does one explain the motion of Mars?

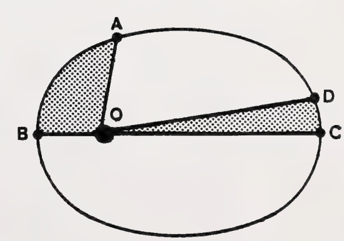
When Kepler began work on the problem he was sure that the solution would not take long — eight days he thought. He ended up taking years. His task would have been impossible without Brahe's accurate observations. For three years he worked hard at the problem. For three years the solution lay almost under his nose but he would not or could not recognize it because he was yet committed to the use of perfect circles and epicycles. He tried 71 different solutions, even creating new mathematics to do the solutions. Using Copernicus' sun-centred system with circular orbits, eccentrics and equants he found an orbit that matched the observations to within eight minutes of arc (0.13°). But Tycho's observations were accurate to within two minutes of arc (0.03°). Finally it came to him that the orbit could not be a circle. There were only two other choices — the orbit had to be an oval or egg-shape with a single centre or it had to be an ellipse with two centres (foci).

Kepler's dedicated search for a solution

Kepler was also interested in finding out about the speed of the planet in orbit. Instead of working first with the question "What combination of circles will describe the orbit of Mars?" he asked the questions, "What shape is Mars orbit?" and "How does it move in its orbit?" These questions proved much more fruitful. It is more productive to ask a good question than to find a good answer to a poor question. For two thousand years astronomers had been committed to a perfect circle. Now Kepler was breaking through to a new understanding. Yet the breakthrough was difficult. The first thing he discovered as he used Brahe's figures was that a line joining Mars to the sun swept out equal areas in equal intervals of time. This gave him the answer to the problem of how fast the planet moved at various times. As it approached closer to the sun, the planet moved faster. As it moved further from the sun it slowed down.

What is the shape of Mars' orbit?

Kepler's first major discovery - The Law of Areas



The areas O DC and O AB are equal. The planet moves faster along AB than along DC since these distances are covered in equal times.

From this law Kepler got support for his idea that the sun was somehow responsible for the motion of the planets. By doing this, Kepler was beginning to deal with physical law — why and how the planets actually move. Up to this point, models of the planets' motions had been designed only for prediction and were concerned with only descriptions of the motion (rather than explanations of it).

Kepler's solution moves beyond description to physical law

Kepler now turned his attention to the shape of Mars' orbit. For several years he tried to fit Mars' positions into an oval-shaped path. He would try now this and now that oval shape. But none of them seemed to work. At one point he lamented to a friend that if only the shape were an ellipse there would be all kinds of information available about it from the Greek geometers. After two years of work it finally came to him. Maybe the orbit was an ellipse. He tried it and it fitted perfectly. Only after he had given up the idea that the curve must have only one centre did he make progress. "I felt as if I had wakened from a long sleep and were blinking at the bright sunlight."* On Easter of 1605 the devout Kepler prayed "Dear Lord who has guided us to the light of Thy glory by the light of nature, thanks be to Thee. Behold, I have completed the work to which Thou hast called me. And I rejoice in Thy creation whose wonders Thou hast given me to reveal unto men. Amen."

The shape of Mar's orbit - discovered 1605

Kepler's final insight into the problem's solution

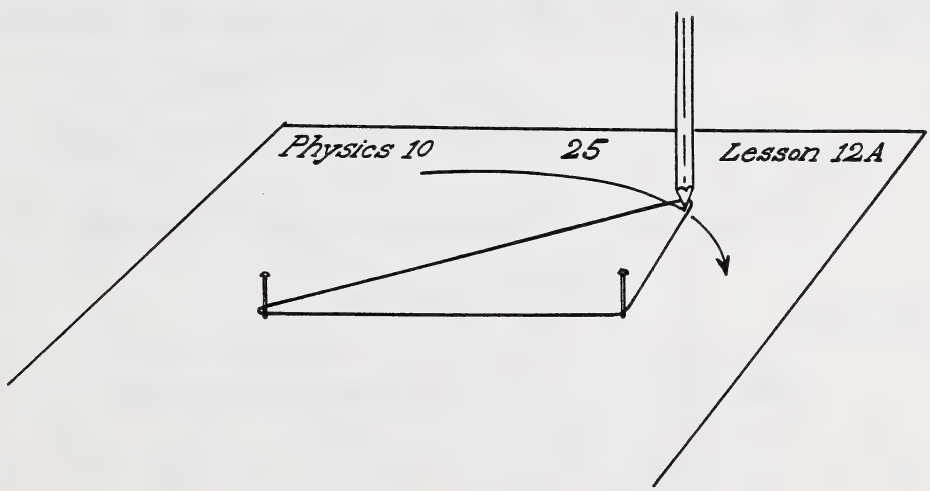
*See Rudolf Thiel, And There Was Light for a fascinating account of Kepler, his personality, life and work.

Activity

The ellipse as the shape of the planets' orbits became known as such only thousands of years after men first tried to fit planetary observations into a geometric model. An ellipse is not really a very complex figure.

To draw an ellipse you need only a wood or fibreboard surface, two straight pins, a length of thread, and a sharp pencil.

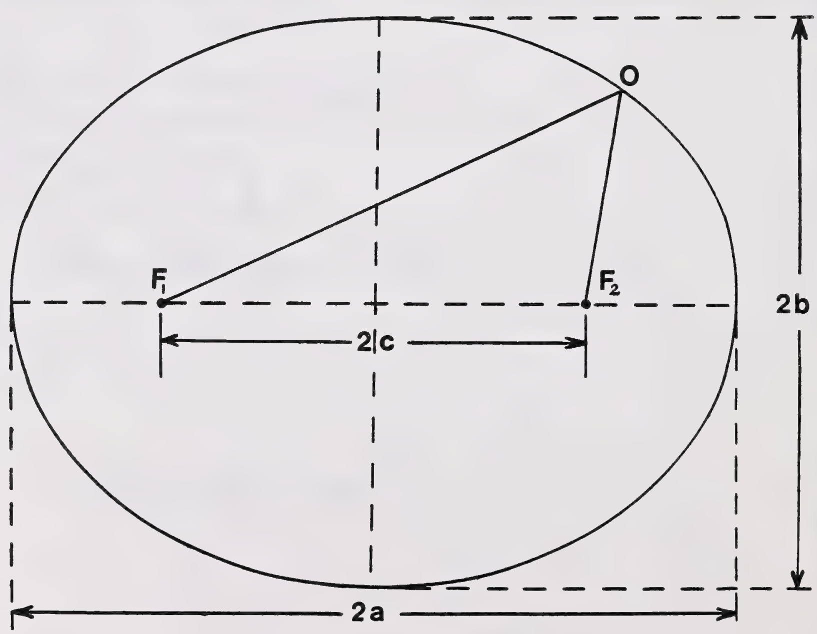
1. Place the top of page 25 on the wood or board.
2. Drive the straight pins into the board through the paper about 6 cm apart.
3. Tie a loop of thread whose closed length is about 2 cm greater than the distance between the pins.
4. Now set up the apparatus as shown in the diagram and draw the ellipse by moving the pencil around until the ellipse is complete.



Constructing an Ellipse

5. Complete your ellipse in the space below.

6. The dimensions and characteristics of an ellipse are shown below.



Major Axis = 2a
Minor Axis = 2b
Distance between foci = 2c

Eccentricity = $\frac{c}{a}$

An ellipse is composed in such a way that the sum of the distances from any point on it to the two foci is constant. That means that F_1 to O to F_2 is always constant and turns out in fact to be equal to 2a.

Find the following measurements for your ellipse in cm.

2a =

a =

2c =

c =

Eccentricity (e) = $\frac{c}{a}$ =

7. Now let's consider Mars as a typical example of a planet with its orbit as an ellipse.

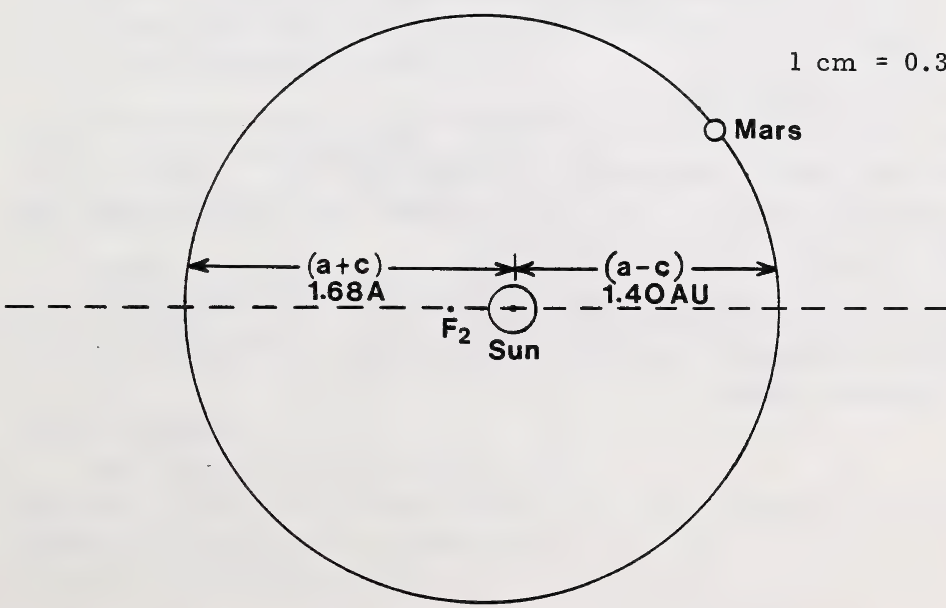
For Mars a = 1.542 AU (astronomical unit - the mean distance from the earth to the sun).
$= 1.542 \times 1.496 \times 10^8$ km $= 2.307 \times 10^8$ km

and e = 0.093

Thus c = 0.093 x a = 0.093(1.542 AU) = 0.143 AU

Thus Mars' orbit to scale would be as follows:

1 cm = 0.34 AU



Note how close the orbital path appears to be to a circle. To find that it is an ellipse, as Kepler did, takes both accurate observation and calculation, which required the best skills of both Brahe and Kepler.

Many of the planets have even smaller eccentricities in their orbits. Remember that the smaller the eccentricity the closer the orbit is to a circle (the eccentricity of a circle is zero).

Planet	Eccentricity
Mercury	0.206
Venus	0.007
Earth	0.017
Mars	0.093
Jupiter	0.048
Saturn	0.056
Uranus	0.047
Neptune	0.009
Pluto	0.250

Which planets have the most eccentric orbits? Which the least?

We can state the two laws that Kepler discovered as follows:

Kepler's first two laws of planetary motion

1. The orbit of a planet around the sun is the shape of an ellipse with the sun at one focus.
2. A line joining the sun to a planet sweeps out equal areas in equal time intervals as the planet moves in its orbit.

These simple laws are the result of six years of intense work by Kepler. They represent simple mathematical descriptions of planetary motion. They are <u>empirical laws</u> based directly on observations. Later Newton would propose a more comprehensive <u>theoretical law</u> which would include these laws of Kepler, and offer a physical explanation (not only a description) of planetary motion.

Empirical laws

Theoretical laws

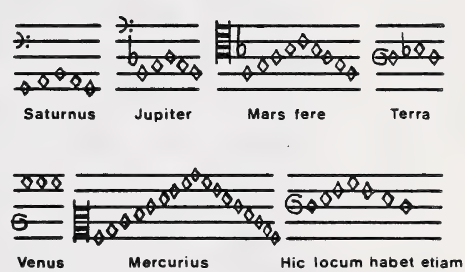
With the first law above we can find all the possible positions of a planet if we know its ellipse. With the second law we can find the speed of the planet at any position. With a combination of the two and a starting observation we can determine the planet's position any time in the past or future.

Kepler's laws can be used to predict a planet's position accurately

Kepler began to wonder later in his studies whether there was some way of relating the motions of the planets to each other. Each planet had its own ellipse but how were they related? Kepler here was exercising an important scientific principle — that nature is understandable and that we can find what the truth about nature is if we continue to search. Out of this question he derived a third law of planetary motion. He found that the squares of the periods of the planets are proportional to the cube of their average distances from the sun. Kepler was so impressed by these simple proportions that he went on to try to discover if the planets' motions could be compared to a musical scale. He was in fact able to ascribe a tune to each of the planets. The whole system of planets could be compared to an orchestra, each playing its proper harmonies. The results of this and his Third Law were published in the book Harmony of the World.

How are the planets' motions related?

Kepler's Third Law of Planetary Motion



After he learned of the telescope, Kepler took some time off to write a study of optics. His book was used as an optics text for some years.

Kepler was a tireless, persistent and inspired scientist and mathematician whose contributions to astronomy are of immense value to us.

Galilei Galileo

While Kepler was working on the motions of Mars, an Italian named Galileo was working on a different yet equally important problem.

Galileo (1564 - 1642)

Galileo was born in 1564, a few years before Kepler, in quite a different part of the world — Italy. He trained first to be a doctor but it soon became clear that mathematics and experiments with objects in nature were his real talent. He became a teacher and a very good one, for his lectures attracted many students, partly because he demonstrated to his students what he taught. They could observe with their own eyes the things that he told them in his teaching. For Galileo it was not good enough simply to declare something. It was also necessary to observe nature and demonstrate her behavior whenever possible. Galileo made many discoveries but there are two that are of special interest to us.

Doctor

Mathematician

Teacher

Experimenter

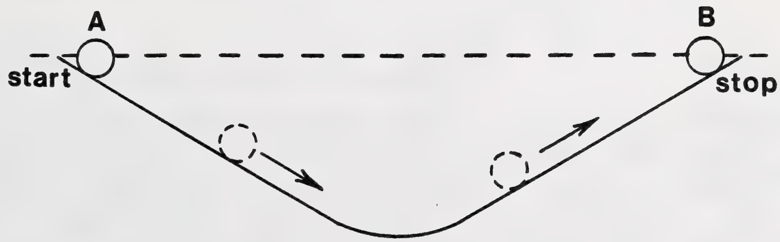
One of the difficulties in accepting Copernicus' idea of the earth's moving around the sun was the proper understanding of motion itself. Why do things move or not move? What makes objects come to rest? Aristotle thought that a continuous force was needed to keep an object in motion. Galileo became curious about this question when he noticed a chandelier swinging in a cathedral. He noticed that even though the swings became shorter, the time for each swing stayed the same. It occurred to him that the swinging chandelier was an example of falling. Later he discovered that all objects fall at the same rate of acceleration, contrary to what Aristotle had taught. To discover how objects fall, he slowed down the rate of falling by rolling objects down an inclined plane. We noted how this was done in Lesson 4. Thus Galileo began to discover why objects move.

What causes motion?

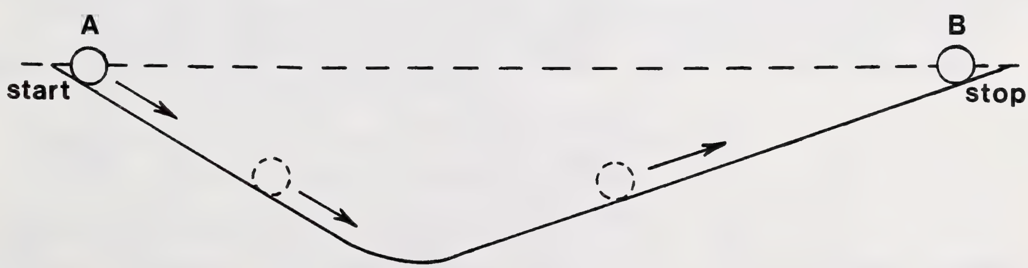
Swinging chandeliers

Balls on inclined planes

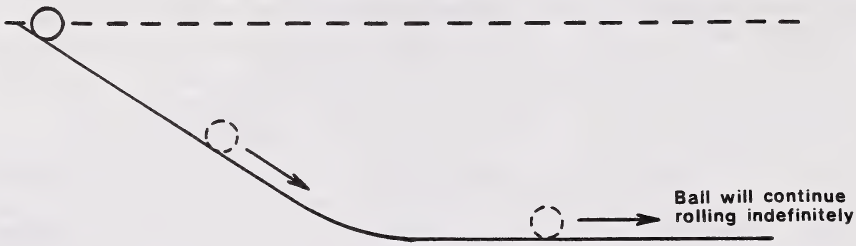
Very early in these experiments Galileo discovered that when a pendulum swings or a ball rolls down one plane then up another, the object always ends up as high as it started out, if there are no other forces acting. Thus in the diagram below, the ball starts at A and ends up at B, at the same level as A.



This happens no matter how sharply or flatly the plane on the right is inclined.

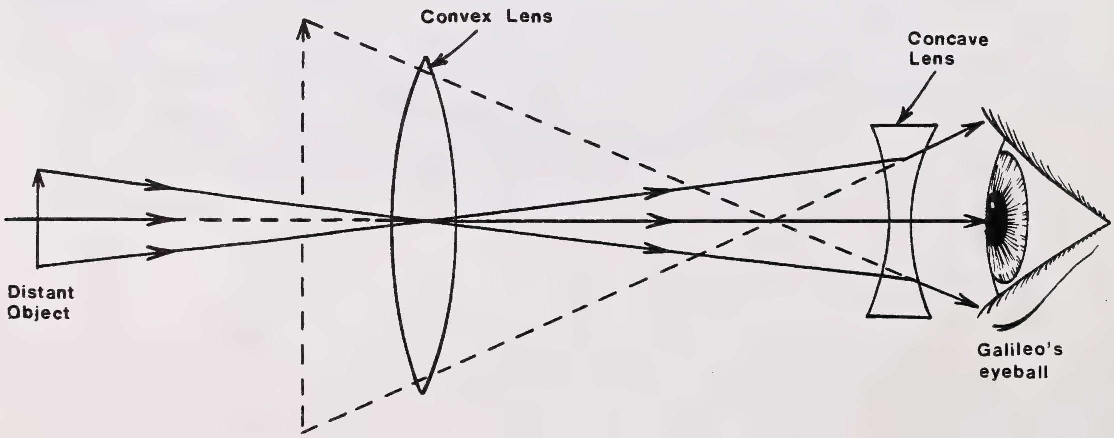


Galileo then asked himself a question which he could not really test, but which was based solidly on the results he had seen so far. What if the plane on the right is made completely flat? Obviously the ball will never reach the same level as it started out because the plane never causes it to rise. That means that the ball will go on moving forever.



This very simple yet amazing observation was the key to the moving earth. The earth continued to move because nothing was there to stop it. It needed no force to keep this motion constant. It would need a force only to slow it down or speed it up. Thus Galileo had discovered an important bit of evidence to support the possibility of Copernicus' idea of a moving earth — the principle of inertia.

A second major discovery, very exciting indeed, to himself and the people of his time, came in 1610. Somewhere he had got word from Holland of an interesting new device. Someone had put two lenses together, one in front of the other, while observing a distant cathedral spire. To the observer's surprise, the spire appeared much nearer and larger than it actually was. Galileo immediately put two lenses together inside a tube and made his first telescope (of about three power). He experimented until he had a telescope of about thirty-three power. Immediately upon pointing it at the moon Galileo discovered the rough-cratered surface with mountain shadows, bright peaks and craters. The moon was not smooth and perfect as most people had supposed. He also discovered that the stars were not magnified but simply became brighter



Galileo's Telescope

points of light. This supported the view that the stars were very distant, and thus would show no parallax with a moving earth. When he observed the Milky Way he saw that it consisted of a myriad of tiny stars and he wrote:

Galileo's observations:

—moon - crated

—stars - points of light

—Milky Way - myriad of stars

> "I know now what the silver girdle around the celestial sphere is; I am filled with amazement and offer unending thanks to God that it has pleased Him to reveal through me such great wonders, unknown to all the centuries before our time."

In his telescope, the planets appeared as small round discs. Most surprising of all, the planet Jupiter showed three small stars beside it in a line. The next time he observed it the stars had changed positions. Shortly he discovered a fourth star that, together with the other three, sometimes appeared and then disappeared in different combinations. The only conclusion he could reach was that here were four heavenly bodies all spinning rapidly about their mother planet, Jupiter. Here was a miniature solar system — a bit of evidence that clearly demonstrated that Copernicus' idea of a family of planets swinging around the sun could be true. It also demonstrated that the earth was not the centre of all heavenly motions. Galileo also foolishly or ignorantly observed the sun through his telescope directly, blinding himself for about a week and permanently damaging his eyesight. Eventually he went blind, perhaps partly because of this incident. Later, using a projection of the sun's image on a sheet of paper, he was able to oberve sunspots and detect the sun's rotation. He also observed the phases of Venus, thus demonstrating that planets shine by reflected light.

—planets - small, round discs

—Jupiter - four moons

—sun - sunspots

—Venus - phases

Galileo's telescope was powerful enough to show that there was something different about Saturn, but the telescope was not powerful enough to show clearly what it was. To Galileo, the planet appeared to have horns. It was not until much later that it became clear that Saturn's unusual feature was a set of rings circling the planet. All of these were new discoveries — none had ever been seen before by the many observers who had been studying the heavens for thousands of years. Galileo could well stand in awe of the many unusual astronomical happenings that he was privileged to observe first.

Saturn's unusual shape

As a result of his experiments and discoveries, Galileo became a thoroughgoing supporter of Copernicus. To support the Copernician model he wrote several popular and interesting books. Yet, though it was 80 years since Copernicus, there was still much resistance to the new idea. Galileo was also a faithful son of the Catholic Church and was much disappointed when it did not respond favorably to the new evidence to support Copernicus. Eventually opposition to Galileo began to grow and he was finally forced in his old age to recant his views which were considered heretical because they differed from Aristotle. This became something of a tragic blot on what was otherwise a brilliant career for this great scientist and thinker.

Two of Galileo's books:
"The Starry Messenger"
"Dialogue Concerning the Two Chief World Syste

Although Galileo went a long ways toward discovering the great fundamental principles of physics that describe the motions of the universe, it remained for another man to put everything together. In the year Galileo died, 1642, Isaac Newton was born.

Isaac Newton (1642 - 1727

Kepler had discovered the laws of heavenly movements. Galileo had studied the motions of objects on earth and made observations to support Copernicus' view of the sun at the centre of the planets. Isaac Newton was to join the two great ideas together to form the theory of universal gravitation by which we today describe and explain the changing universe and its motions. But that begins another story. Following the age of Copernicus, Brahe, Kepler, Galileo and Newton there were many fascinating developments in the study of astronomy. Galileo, however, brings us to the end of our Physics 10 journey which has taken us to the major discoveries that helped form a foundation for modern astronomy — the discovery of the laws of planetary motion and the discovery of the telescope.

Universal Gravitation

Lesson Summary

Hipparchus was the only great observational astronomer of ancient Greece. He prepared a catalogue of 800 stars and invented the system of classifying stars by magnitude.

Ptolemy's model of the universe involved a complex set of deferents, epicycles, and equants. With the observations then available, it was reasonably accurate in describing and predicting planetary positions. It was an earth-centred model.

The Arabs adopted Ptolemy's model and preserved much of the astronomical knowledge that came through the Greeks. They perfected the use of navigation instruments, especially the astrolabe.

Clocks were the first mechanical models of the universe. They were first invented and used in ancient China. The invention of clocks gave rise to the concept of an even flow of time, hour by hour, to replace the conception of uneven time flow that came from the use of the sundial.

Copernicus stood at the beginning of what we call the modern era of astronomy. If the earth spins on its axis and moves around a central sun, we can easily explain the daily sky motion, the change of the sky through the seasons and the planetary loops.

Tycho Brahe was a very skilful instrument builder and observer who made precise observations on the positions of hundreds of stars and plotted very carefully the motions of the planet Mars. He also devised a model of the planets that preserved the earth at the centre.

Johannes Kepler, a persistent and skillful mathematician discovered the three laws of planetary motion using Brahe's accurate observations. The three laws are:

1. The orbit of a planet around the sun is an ellipse, having the sun at one focus.

2. A line from the sun to a planet sweeps out equal areas in equal time intervals.

3. The squares of the periods of the planets are proportional to the cubes of their average distances from the sun.

Galileo was the first astronomer to use a telescope. Through it he saw the mountains of the moon, the phases of Venus, the unusual shape of Saturn, the spots on the sun and the moons of Jupiter. Many of these observations supported Copernicus' idea of a sun-centered system of planets. Galileo also made some important discoveries about motion and discovered the principle of inertia.

Review Exercises

1. What observation led Hipparchus to suggest an eccentric path for the sun around the earth?

   (a) The faster motion of the sun at some times of the year than others.
   (b) The inclination of the earth's axis, which calls for variations in distance.
   (c) The seasons — the sun must be closer at sometimes to produce greater heating effects.
   (d) The apparent diameter of the sun changes. ______

2. Ptolemy's astronomy was largely based on two previous astronomers. Who were they?

   (a) Apollonius and Hipparchus
   (b) Anaximander and Aristarchus
   (c) Aristarchus and Hipparchus
   (d) Eratosthenes and Apollonius ______

3. An instrument which the Arabs perfected and used widely was the

   (a) sundial.
   (b) armillary sphere.
   (c) quadrant.
   (d) astrolabe. ______

4. One of the main difficulties Copernicus experienced in using his new sun-centered model to describe and predict the planet positions came because of

   (a) no observations to work with.
   (b) a lack of time to study it carefully.
   (c) inaccurate observations from the past.
   (d) no support for his labors from other astronomers. ______

5. Which of the following is a major objection to Copernicus' sun-centered model?

   (a) the planetary loops
   (b) the lack of parallax among the stars
   (c) the daily apparent rotation of the sky about the earth
   (d) the apparent uneven seasonal motion of the sun ______

6. Brahe's early interest in careful astronomical observation was partly stimulated by

   (a) the influence of Hipparchus.
   (b) the occurrence of a supernova.
   (c) the publishing of Copernicus' book.
   (d) Galileo's telescope. ______

7. How did Brahe increase the accuracy of his observations?

   (a) By using large instruments.
   (b) By using a telescope.
   (c) By more careful timekeeping.
   (d) By moving further north. ______

8. One of Brahe's major instruments was

   (a) the astrolabe.
   (b) the quadrant.
   (c) the gnomon.
   (d) the armillary sphere. ______

9. What statement best describes how Kepler discovered the laws of planetary motion?

   (a) By a stroke of intuition.
   (b) By a line of lengthy but clear and error free reasoning.
   (c) By long and tedious calculation.
   (d) By extended discussion and meditation. ______

10. What did Galileo contribute in a major way to the Copernician model of the universe?

    (a) greater precision in observations of the planets and stars
    (b) strong evidence from observations both in the heavens and on earth
    (c) popular writing supporting the Copernician view
    (d) application of mathematics to the study of heavenly motions ______

11. What did Brahe hope to gain from taking on Kepler as an assistant?

    (a) new ideas on improving accuracy of observations
    (b) a new model of the planetary motions
    (c) support for his own model of planetary motion
    (d) help in his task of collecting precise data ______

12. What was it that may have left Hipparchus dissatisfied with previous astronomical records?

    ____

    ____

13. What reason did Copernicus give for rejecting the equant proposed by Ptolemy?

    ____

    ____

14. Why could Copernicus be called a "quiet revolutionary?"

____

____

____

15. Why did Kepler change his mind about using circles to determine Mars' orbit?

____

____

16. Following are six arguments against the Copernician system of sun and planets:

A. Copernicus' model is no simpler than Ptolemy's in the calculations required to predict planet positions.

B. In Copernicus' system the earth goes around the sun but the moon goes around the earth. Ptolemy's is simpler in that everything goes around the earth.

C. There should be shifts in star positions (stellar parallex) if the earth goes around the sun. There isn't any.

D. Copernicus could show no information to support the revolving or the rotating earth. In fact ordinary experience seems to tell us clearly that the earth does not move.

E. The sun-centered view of the universe was contrary to Aristotle and thus also to some viewpoints of theologians who used Aristotle as a basis for their thinking.

F. Copernicus' view called into question the uniqueness of man. If the earth is not the centre then there may be life elsewhere.

(a) Which of the above arguments are based on observations?

____

(b) Which are based on philosophy or philosophical preferences?

____

(c) Which are based on religious understandings of man and the universe?

____

(d) Please look at argument (B) above. How did either Kepler's or Galileo's work support Copernicus?

---

17. Halley's comet has a mean distance from the sun of 18 AU. It was last seen in 1986. The eccentricity of its orbit is 0.97.

(a) What is the period (the time it takes to go once around the sun)? (Use Kepler's Third Law $k = \frac{T^2}{R^3}$. If T is in years and R is in astronomical units then k = 1).

(b) What is its greatest distance from the sun? (Study the ellipse on page 26 to discover how you can find this — remember that the sun is at one focus of the ellipse and that the mean distance from the sun is given by 'a'. Give your distance in AU — astronomical units.)

Solution

$d = a + c \qquad e = c/a \qquad \text{so} \qquad c = ea$

$$d = a + ea = a(1 + e) = 18\text{ AU }(1 + 0.97) = 35.5\text{ AU}$$

(c) What is its least distance from the sun?

Hint: $d = a - c$

(d) In what year would we expect Halley's comet to appear again?

18. It is interesting to calculate the speed of the earth at the equator. The earth's radius is 6380 km. This is the radius of the circle that a point on the equator describes in one day.

(a) How fast in km/h does a person standing at the equator move with respect to the center of the earth?

$$r = 6380 \text{ km}$$

$$t = 24 \text{ h}$$

$$V_{eq} = \frac{d}{t} = \frac{2\pi r}{t} = \frac{2\pi 6380 \text{ km}}{24 \text{ h}} = 1670 \text{ km/h}$$

(b) Why does he not fly off from the equator if he is moving at that speed?

____

____

(c) Why is it an advantage to have rocket sites near the equator?

____

____

(d) In what direction should you launch the rocket?

____

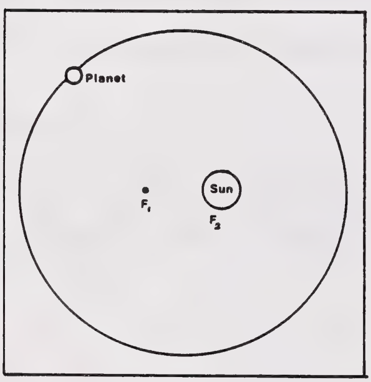
(e) Using a similar calculation to (a) above find the speed of the earth in its orbit (in km/h) with respect to the sun. The mean radius of the earth's orbit around the sun is 1.495×10^8 km.

19. Match the following men with the discoveries that they made. You may use each name more than once.

A. Kepler
B. Brahe
C. Copernicus
D. Galileo
E. Newton

_______ first saw the four brightest moons of Jupiter
_______ retained an earth-centered universe
_______ combined motion in the heavens and motion on earth under one theory
_______ made outstandingly accurate observations of the heavens
_______ discovered some laws of falling bodies and acceleration
_______ tried unsuccessfully to detect parallax
_______ discovered laws of planetary motion
_______ placed the sun at the centre of the universe

20. Each of the following represents a model of planetary motion put forth by one of the astronomers we have studied in this elective. Identify each model by writing below it the name of the man who is associated with it.



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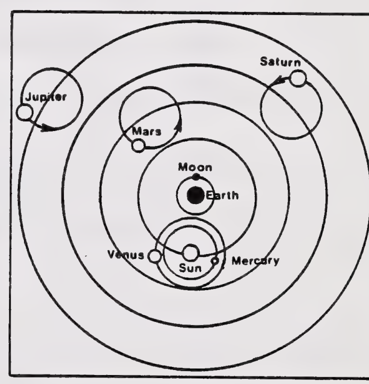

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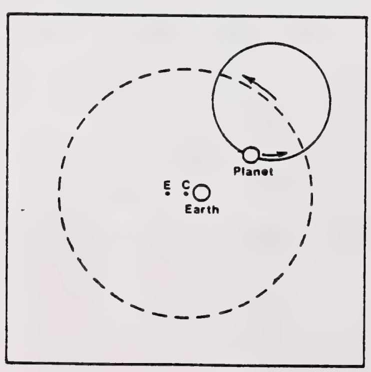

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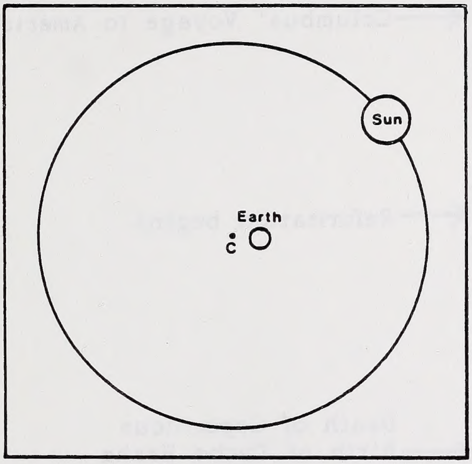
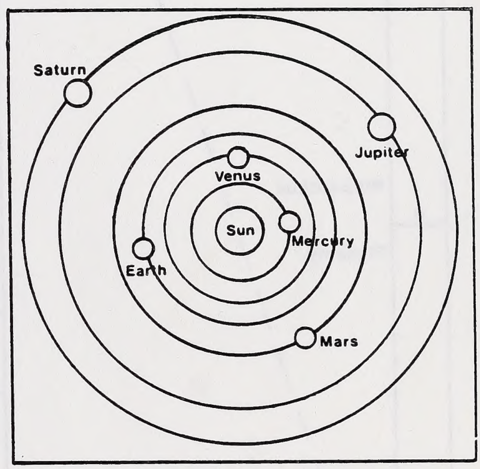
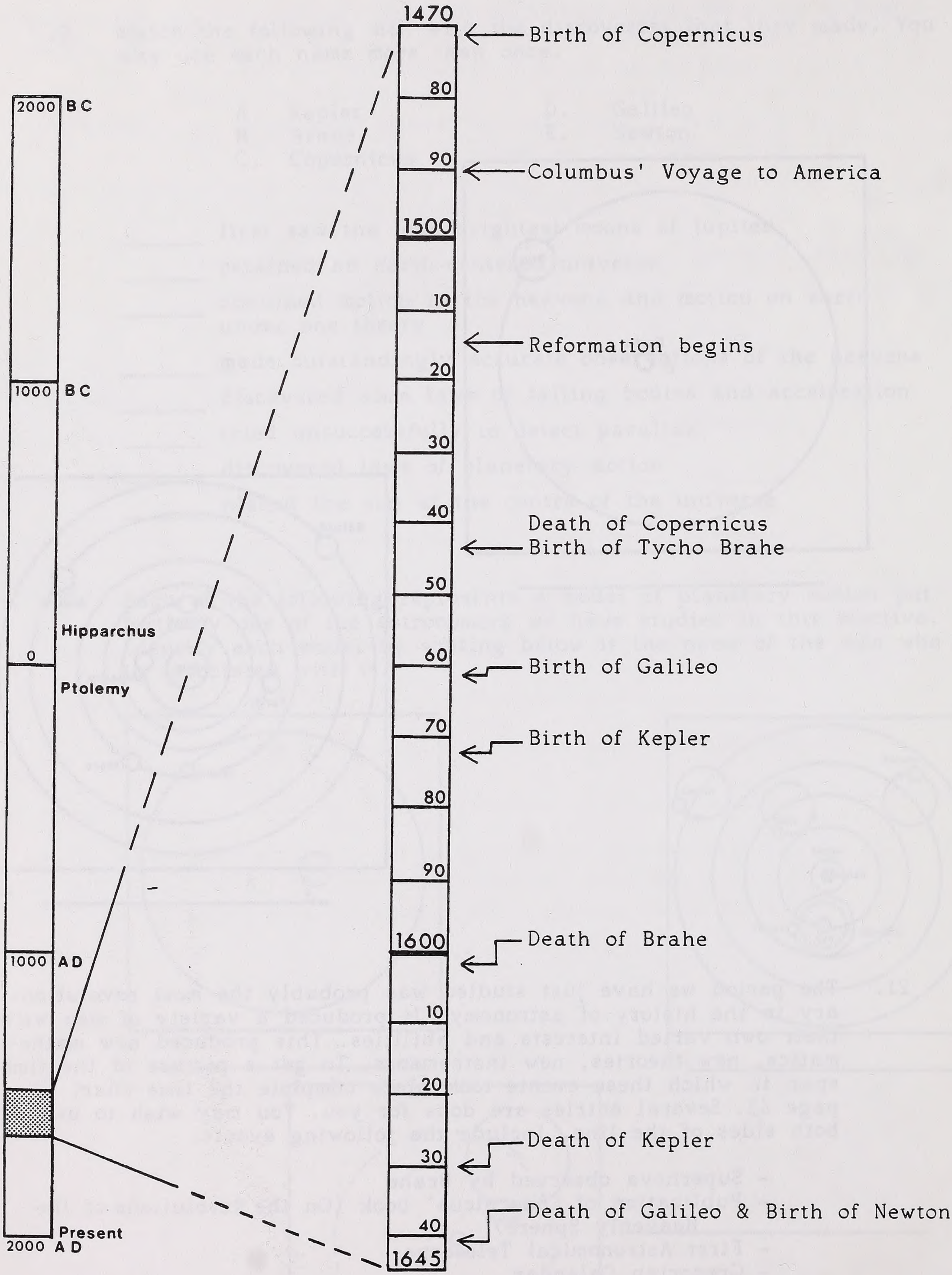




21. The period we have just studied was probably the most revolutionary in the history of astronomy. It produced a variety of men with their own varied interests and abilities. This produced new mathematics, new theories, new instruments. To get a picture of the time span in which these events took place complete the time chart on page 43. Several entries are done for you. You may wish to use both sides of the line. Include the following events:

- Supernova observed by Brahe
- Publication of Copernicus' book (On the Revolutions of the Heavenly Sphere)
- First Astronomical Telescope
- Gregorian Calendar
- Kepler discovers Mars' orbit is an ellipse.



End of Lesson 12A